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NEURO-ANATOMY

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PREFACE

In few other fields of medicine is a detailed knowledge of anatomy more necessary than in neurology With the present rapid strides in neurophysiology, a thorough understanding of neuro-anatomy is increasingly important This book attempts, in condensed outline form, to present the basic anatomy of the nervous system with which the practising physician must be familiar to properly interpret the symptomology of nervous disease

As an outline, it is hoped it will aid the beginning student to become oriented in his study of more extensive source books and journals By its use as a review, perhaps the advanced student may re-acquaint himself more easily with the anatomical background of his physiological and clinical studies In this latter sense, if the general practitioner also finds it of value, the author will be well satisfied

In bringing together in this outline recently ascertained facts with those long established, the author has striven for accuracy, and it is hoped that such brief outline form has not bred mis-statement Since controversial issues and conflicting data have been of necessity omitted, some findings of considerable interest may have received less than deserved attention

In the outline's preparation, the student's difficulties in properly organizing the vast array of factual data with which he is confronted, have been borne constantly in mind

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I

NEURO-ANATOMY

I. THE NERVOUS SYSTEM includes all of the nervous tissue of the body, the nerves and peripheral plexuses as well as brain and spinal cord It is an irritable system composed of an

A. Afferent Division, subserved by sensory organs and endings, responsive to stimuli

B Integrative Division, which marshals the extent and disposition of nervous response

C. Efferent Division, which innervates the muscles and glands.

II CLASSIFICATION

A. Peripheral Nervous System.

1 The Spinal Nerves include thirty-one pairs, relatively uniform Their segmental arrangement (which is partially obscured by brachial and lumbosacral plexuses) is more obvious in cutaneous than in muscular distribution They consist of

a Dorsal afferent root and ganglion

b Ventral efferent root

c. Common mixed trunk

d. Dorsal and ventral primary rami

e. Muscular and cutaneous branches

f Each trunk has a *gray ramus communicans* and the first thoracic through the second lumbar trunks have white rami, communicating with the sympathetic ganglia

2. The Cranial Nerves consist of twelve pairs, of diverse types and with obscure segmentation They include nerves of special sense and to branchial arch muscles as well as general components

3 Autonomic Nervous System. Consists of a paired and an unpaired series of ganglia as well as integral parts of cranio-

spinal nerves and central nervous system. It is the *efferent* system to smooth muscle, cardiac muscle, and glands

a. Sympathetic division Consists of the paravertebral ganglionic chains, the prevertebral ganglia, and the efferent components of the white and gray rami communicantes wherever distributed in central and peripheral nervous systems

b Parasympathetic division.

(1) Cranial outflow Consists of the general visceral efferent component of the vagus nerve with all its terminal ganglia in thoracic and abdominal viscera, as well as four paired cranial ganglia associated with components of other cranial nerves

(2) Sacral outflow The pelvic visceral nerve with its terminal ganglia

4 The Visceral Nervous System consists of the autonomic system together with the accompanying visceral afferent fibres

B Central Nervous System. The spinal cord and brain occupy the vertebral canal and cranial cavity, from the walls of which they are separated by the meninges and the cerebrospinal fluid

1 The Spinal Cord and Brain Stem contain the motor column from which the efferent nerve roots take origin, and the association column in which end the afferent roots

2. The Cerebellum, Colliculi, and Forebrain contain the higher integrative mechanisms

III. NEUROLOGY, the study of the nervous system, includes

A. *Morphology Structure of the nervous system*

1 Gross Anatomy, the arrangement of the nerves and larger features revealed by dissection

2. Microscopic Anatomy, the study of nervous pathways and cellular arrangements

3 Histology, the structure of neurones and neuroglia

4 Embryology, the histogenesis of cellular elements as well as development of cellular and fibre arrangements

5 Comparative Neurology, the phylogenetic comparison of the nervous systems of all animals

B Physiology Functional aspects, reflex physiology, excitability, conduction, etc

C. Pathology Study of disease process and structure.

D Clinical Neurology The symptomology of nervous disease and other injury

E. Neuro-anatomy, as a medial course, is chiefly concerned with the central nervous system It draws its material from the above neuromorphological fields. Contributions from physiology, pathology, and clinical neurology are included only where directly pertinent to the anatomical material

IV THE NEURAL TUBE.

A. Development. The embryonic nervous system appears as a thickened ectodermal neural plate bounded by two neural folds. Fusion of folds forms the neural tube and two dorsolateral strands of neural crest. The larger anterior end of the tube is divided by two constrictions into three brain vesicles, prosencephalon, mesencephalon, and rhombencephalon The first becomes redivided into telencephalon and diencephalon, and the third redivided into metencephalon and myelencephalon The posterior portion of the neural tube is the future spinal cord. Paired evaginations of the telencephalon form the cerebral hemispheres while the optic vesicles arise as ventrolateral outpocketings of the diencephalon The lumen of the neural tube becomes the ventricular system

B Derivatives.

1 Prosencephalon (Forebrain)

a. Telencephalon

(1) Derivatives.

(a) Pallium (cerebral cortex)

(b) Corpus striatum.

(c) Olfactory lobe.

(2) Nerve Olfactory Cr I

(3) Lumen

(a) Two lateral ventricles

(b) Anterior part of third ventricle.

b Diencephalon.

(1) Derivatives.

(a) Thalamus and metathalamus.

(b) Epithalamus
(c) Subthalamus
(d) Hypothalamus, optic chiasma, mammillary bodies, posterior lobe of pituitary body
(2) Nerve Optic nerve
(3) Lumen Third ventricle (greater part of)

2. Mesencephalon (Midbrain)
(1) Derivatives
(a) Corpora quadrigemina (colliculi)
(b) Basis pedunculi.
(c) Red nucleus, substantia nigra, and tegmentum
(2) Nerves
(a) Oculomotor—Cr III
(b) Trochlear—Cr IV
(3) Lumen Cerebral aqueduct (Sylvian isthmus)

3 Rhombencephalon (Hindbrain)
a. Metencephalon (Pons)
(1) Derivatives
(a) Pontine tegmentum
(b) Pars basilaris pontis
(c) Cerebellum
(2) Nerves.
(a) Trigeminal nerve—Cr V
(b) Abducens nerve—Cr VI
(c) Facial nerve—Cr VII
(d) Auditory (cochlear and vestibular) nerve—Cr VIII
(3) Lumen Fourth ventricle (anterior half)
b Myelencephalon (medulla oblongata)
(1) Derivatives Medulla oblongata
(2) Nerves.
(a) Glossopharyngeal—Cr IX
(b) Vagus—Cr X
(c) Spinal accessory—Cr XI
(d) Hypoglossal—Cr XII
(3) Lumen Fourth ventricle (posterior half)

4 Posterior Portion of Neural Tube
a Spinal cord

(1) Derivatives.
(a) Motor column
(b) Association column
(c) White columns
(2) Nerves
(a) Spinal nerves (31 pairs)
(b) Spinal root of spinal accessory—Cr XI
(3) Lumen Central canal

C. Gross Structure of Neural Tube. In cross section the tube is seen to consist of thin floor and roof plates, and thick lateral walls All nervous tissue develops in the lateral walls, the roof and floor remaining non nervous

1 Floor Plate Thin and narrow in the cord, it becomes the median raphe of the hindbrain, at the anterior end of which it ends

2. Roof Plate. Narrow in the cord, it becomes the wide thin roof of the fourth ventricle, and the tela chorioidea of the third ventricle

3 Basal Plates. Thick, paired longitudinal columns, they are ventrolaterally placed on each side of the floor plate They extend throughout the cord, hindbrain and midbrain, giving rise to all the motor nuclei of the cerebrospinal nerves

4 Alar Plates The dorsolateral walls of the neural tube are separated from the basal plates by the *sulcus limitans* They extend the full length of the tube, forming the association column in which end the afferent nerve roots They expand in the brain to form the cerebral hemispheres, as well as cerebellum and corpora quadrigemina

5 Sulcus Limitans A mid lateral groove, extending throughout the cord, hindbrain, and midbrain, separates the basal from the alar plates, and ends ventrally between midbrain and forebrain

D Cellular Structure of the Neural Tube. Three well defined layers make up the wall

1 Ependymal Layer The lining of the tube is a proliferating germinal epithelium, whose mitotic products migrate outwards to form the mantle layer

2. Mantle Layer Thick and multicellular, it consists of defini

tive neuroblasts and spongioblasts which develop into neurones and neuroglia

3 Marginal Layer The outer layer is at first non nucleated, later neuroglia migrate in The long axons of association neurones leave the mantle to form tracts in the marginal layer

4 Cortex. A fourth layer is produced in the cerebrum and cerebellum by migration of mantle elements across the marginal layer to form a peripheral cortex

5 Gray and White Matter Myelinization of the tracts of the marginal layer makes it appear white, the unmyelinated mantle elements remaining gray Hence the cellular aggregations such as cortex and nuclei are the gray matter, and the great pathways in the marginal layer form the white matter

E. Histogenesis and Histology The embryonic mantle layer consists of neuroblasts and spongioblasts derived from the ependyma

1 Neuroblasts Each develops into a single nerve cell or neurone

a Axon Each neuroblast first produces a *growth cone* which grows out to form the long thin axon of uniform diameter

b Dendrite. Other processes grow out to form short, tapering, highly branched dendrites

c. Neurofibrillae. Internally the cytoplasm produces fine fibrillae which are long and thin in nerve fibres, and interlace in the cell body

d Nissl substance. Between the neurofibrillae many small darkly staining Nissl 'granules' are formed

e. The nucleus is large and vesicular, with a prominent nucleolus

f Axon hillock. The axon arises from a small clear cone or hillock, and ends usually in fine branching filaments called *Telodendria*

g Collaterals or side branches of the axons usually are few and leave at right angles

h Bipolar neurones have only one dendrite as well as the

one axon They are found in the retina and in the eighth nerve ganglia

i Monopolar neurones have an axon only which branches in a T fashion They are found in spinal ganglia

j Multipolar neurones have many dendrites and are found throughout the central nervous system, and in the autonomic ganglia

k Golgi Type I cells have long, and Type II short axons

2. Spongioblasts. Form the supporting tissue

a Protoplasmic astroglia have many thick branching processes, and are found in the gray matter

b Fibrous astroglia have long thin branches, are found principally in the white matter Astroglia of both types have processes ending as perivascular feet on blood vessels

c. Oligodendroglia are small with few branches In the gray matter they are closely applied to neurones as satellites In white matter they form rows closely investing the axons

d. Microglia Mesodermal elements, very small, which penetrate both gray and white matter from outside. They probably act as scavengers in cell injury (neuronophagia)

e. Ependyma When proliferation ceases, the remaining columnar epithelium forms the lining of the central canal and ventricles Embryonically each cell has a ciliated border and a long basal process reaching out to the external limiting membrane The latter condition is seen in the adult only in the ventromedian sulcus and raphe

f External limiting membrane. Consists of neuroglia closely applied to the inner surface of the pia (pia-glial membrane), and accompanies cerebral blood vessels a short distance into the brain

V NEURAL CREST Consists of a dorsolateral strand on each side of neural tube, at first continuous, later segmented in relation to somites It forms a variety of elements

A Spinal Crest.

1 Neuroblasts At first bipolar, they later become unipolar neurones The axon process divides, the thick peripheral process going to skin, muscle or viscera, terminating as a sensory ending, the thinner central process entering cord

2 Sheath Cells They migrate from crest along both afferent and efferent neurones, to form *neurilemma* sheath of peripheral axons

3 Pericellular Capsule Surrounding each ganglion cell is a multicellular capsule continuous with the neurilemma

B Cranial Crest It gives rise to mesectodermal structures as well as neuroblasts and sheath cells Thickened ectodermal patches, the epibranchial placodes, also contribute to the cranial ganglia

1 The Crest forms neurones of the general cutaneous system, in ganglia of Cr V, and a smaller number in Cr VII, IX, and X

2 The Epibranchial Placodes give rise to visceral afferent components of Cr VII, IX, and X

3 The Otic Placode gives rise to the bipolar neurones of Cr VIII as well as the internal ear

4 The Crest contributes sheath cells to the cranial nerves

5 The branchial arch cartilages are mostly from crest

C The Paravertebral and Prevertebral Ganglia of the sympathetic system are probably of crest origin also, as is the adrenal medulla

VI MYELINIZATION

A Classification Axons may be naked, or covered by either a myelin sheath or a neurilemma sheath, or both

1 Naked Fibres. In central gray, intra-cortical neurones, and some of the longer tract fibres in cord and brain

2. With Myelin Sheath Most of the larger axons of central nervous system

3 With Neurilemma Many small fibres of peripheral nerves (Remak s fibres)

4 With Myelin and Neurilemma The larger fibres of the peripheral nerves

B Nature of Myelinization

1 Myelin is a fatty substance which forms a sheath along the

axon, continuous in brain and cord, discontinuous in peripheral nerves In the former, oligodendroglia closely invest the myelin sheath, and in the latter, a sheath cell encompasses the myelin of each nodal segment, which are separated by nodes of Ranvier The sheath cells, and possibly the oligodendroglia are concerned in myelinization

2 Myelinization Sequence. The various nerve pathways become myelinated in a sequence which is comparable to the phylogenetic age of each tract

a First to be myelinated are the *efferent roots* followed by the *afferent roots* in the cervical cord

b Second are the intersegmental (ground) bundles, the spinocerebellar tracts, and the median longitudinal bundle The vestibular portion of the eight nerve myelinates early

c. The corticospinal tracts and corticopontine systems myelinate later, and after birth, while some cortical association areas myelinate only after many years

3 There is some evidence that the pattern of developing function in the foetus is related to the myelinization pattern

VII THE REFLEX ARC. Nervous activity in its simplest form involves a physical change stimulating an afferent ending, a wave of excitation passing along axon to stimulate, across a synapse, a motor neurone which in turn activates a muscle unit Most simple reflex arcs involve also central internuncial neurones (interneurones), and most neural activity involves highly elaborate systems of many neurones and multiple parallel circuits

A The Stimulus is a physical change, such as pressure, light, sound, etc

B Excitation is a local depolarization at an irritable point (usually the sensory ending), which may then be propagated in rapid waves (the *Nerve Impulse*) throughout the whole neurone

C. A Synapse is an area of contiguity between the telodendria of an axon and the dendrites or cell body (soma) of another neurone across which nerve impulses may excite the second neurone

1 Synaptic Terminals In the synaptic region, the axon terminals are frequently applied as minute rings, either ter-

minal (boutons terminaux) or along the course (boutons de passage) of the telodendria

2. Other types include those of the purkinje cells of the cerebellum, which are surrounded by a dense meshwork of axon terminals of basket cells, the climbing fibres extending along the purkinje dendrites, and the mossy endings in the granular layer

D Dynamic Polarity In the laboratory the nerve impulse may travel in either direction along an axon, but the synapse allows an impulse 'to pass' only from the axon of one cell to dendrite or soma of the next

E Self Excitatory Circuits Neural activity of higher brain centers is very complex and may not be reduced to simple circuits The Berger rhythm is partially independent of immediate afferent impulses The goldfish brain, separated from afferent nerves, discharges repeditive central volleys synchronous with respiratory movements Closed self-exciting circuits are a plausible explanation

VIII DEGENERATION AND REGENERATION When an axon is severed, the peripheral section degenerates completely, while the central stump and cell body show transitory changes

A Wallerian Degeneration The peripheral section (away from cell body) degenerates, the myelin becomes chemically changed, forming lumps and granules, and is finally completely resorbed The neurilemma becomes a chain of sheath cells

B Retrograde Degeneration The central stump degenerates back to a node of Ranvier The cell body shows transitory chromatolysis (solution of Nissl granules) and an eccentric nucleus If the injury to axon is close to cell, chromatolysis is severe and the cell may die Injury to the central process of spinal ganglion cells does not produce retrograde degeneration

C. Regeneration Only peripheral nerve fibres regenerate. The chain of sheath cells forms a path along which the new axon, as a bud from the central stump grows out The neurilemma is later re formed from the sheath cell chain Central neurones have no sheath cells and do not regenerate

II

SPINAL CORD

I GROSS ANATOMY

A General Description Consists of an oval column of nervous tissue, with cervical and lumbar enlargements, occupying the vertebral canal, continuous above with the medulla oblongata through the foramen magnum, and terminating below, opposite second lumbar vertebra, as the *conus medullaris* beyond which a thread like *filum terminale* continues to the coccyx

B Sulci Six longitudinal furrows are present the *ventral median, dorsal median,* and paired *ventrolateral* and *dorsolateral* sulci The sulci help to divide the subjacent white matter into three pairs of white columns, the dorsal, lateral, and ventral *funiculi* In the cervical region, each dorsal funiculus is subdivided by a *dorsal intermediate sulcus* (and septum) into a medial *fasciculus gracilis* and a lateral *fasciculus cuneatus*

C. Nerve Roots Thirty-one pairs of roots pass out to the intervertebral foramina

1 Dorsal Roots The spinal ganglia lie in the intervertebral foramina (exception sacral ganglia lie in the vertebral canal), from which the central process of each enters the dural sac, and breaks up into a number of filaments which fan out to enter the dorsolateral sulcus in a continuous longitudinal series The section of cord encompassed by the filamentous expansions of each root pair constitutes a *spinal segment*

2. Ventral Roots Emerging from near the ventrolateral sulcus a group of filaments converge to form the ventral root, pierce the dural sac and join the dorsal root in the intervertebral canal

3 Spinal Accessory Root. In the upper cervical region a series of lateral rootlets emerge to form the cranially directed spinal root of the eleventh cranial nerve

4 Position of Roots In the adult, the spinal cord is shorter

than the vertebral canal, the sacral cord being at the level of the first lumbar vertebra Each successive pair of nerve roots, from cervical to coccygeal, runs further backward (in the dural sac) to reach its appropriate spinal exit The sacral roots, several inches long, run directly backward surrounding the filum terminale and form, within the dural sac, the *cauda equina*

D Meninges. The cord is covered with three connective tissue membranes

1 Pia Mater A delicate vascular membrane closely investing the cord and roots
2 Dura Mater A thick tubular sheath enclosing the cord and occupying almost the whole length of the vertebral canal, from the walls of which, it is separated by epidural fat and blood vessels At the third sacral vertebra it constricts to a thread upon the filum terminale It is pierced by all of the nerve roots and the filum terminale, each of which receive from it an investment
3 Arachnoid A thin, web-like and reticulated, non vascular membrane, close beneath the dura, and separated from the pia by the *subarachnoid space* lined with epithelium, containing *cerebrospinal fluid*
4 The Denticulate Ligament is a bilateral shelf like fold from the pia, with scalloped border extending as teeth to attach to the dura between each pair of spinal nerves It extends from the upper cervical to the lower thoracic region, and serves as a suspensory ligament of the cord

E. Lumbar Puncture. The portion of the dural sac in the lumbar region, containing the cauda equina but not the cord, is safely reached for spinal fluid examination The needle passes in below the fourth lumbar spine, crosses the epidural space, through the dura, subdural space, and arachnoid, to withdrew fluid from the subarachnoid space The needle is unlikely to damage the small mobile nerve roots, of which the ventral will regenerate if injured

II MICROSCOPIC ANATOMY In cross section, the cord consists of a central column of gray matter surrounded by the white funiculi

A. Gray Matter A fluted column, H-shaped in cross-section, of two lateral halves connected by a *gray commissure* containing the spinal canal. Each half consists of a ventral and a dorsal column. The ventral column is essentially the efferent nerve nuclei forming a motor column, the dorsal column is an association column, in which end the afferent nerve roots Outside the cord, the spinal ganglia constitute the afferent column

1 Ventral (Motor) Column. The ventral horn, short and thick, contains the large multipolar cell bodies of all the somatic efferent neurones Their branching dendrites occasionally extend into the white matter or cross in the white commissure to the opposite side. Their axons innervate groups of muscle cells The neurones are arranged in cell groups or nuclei

a. Ventromedial group Contiouous column, absent only in L_5S_1

b Dorsomedial groop T_1 through L_1 The medial cell groups innervate the trunk musculature.

c. Ventrolateral group C_{4-8} and L_2-S_2

d. Dorsolateral group C_{4-8} and L_2-S_3

e. Retro-dorsolateral group C_8T_1 and S_{1-3}

f. Central groop L_2-S_2 The lateral groups innervate the appendicular muscles, and they are primarily responsible for the cervical and lumbar enlargements of the cord

g Phrenic nocleus. C_{3-5}

h. Lateral column. The lateral horn is a lateral extension of the ventral horn in the thoracic and upper lumbar segments It contains the intermediolateral cell group (T_1-L_2) These small multipolar cells are the sympathetic preganglionics A similar group (S_{2-4}) are the preganglionics of the sacral parasympathetic.

i. Spinal nucleus of the Accessory Nerve. C_{1-5}

2. Dorsal (Association) Column. The dorsal horn is thin and attenuated, consisting of a peripheral apex and a central expanded caput, connected to the ventral column by a thinner cervix. It contains many cell groups not well defined, of small and medium sized cells

a. Classification The cells of the dorsal column give rise to fibres which may be classified into
   (1) Intrasegmental Short, unmyelinated, confined to the central gray
   (2) Intersegmental Longer, emerging from gray into the proximal white matter, to reach lower and higher cord regions (ground bundles)
   (3) Suprasegmental. Ascending fibres in the peripheral zone of white matter, to reach higher brain centers

b Apex Contains the *substantia gelatinosa* of Rolando, usually small neurones difficult to stain The marginal zone has large cells few in number, the intermediate zone small fusiform cells, and inner zone stellate cells (Golgi Type II) The substantia gelatinosa extends the whole length of the cord, and continues into the brain stem as the spinal trigeminal nucleus

c. Caput. Contains no well defined cell groups, but many neurones of diverse axon-destination are present

d Cervix. Small irregularly grouped cells In the thoracic and upper lumbar segments a well formed nuclear column of large cells is present, the *dorsal nucleus of Clarke*

3 Reticular Substance. Lateral to the cervix, in the cervical region some gray matter is intermingled with fibres of the lateral funiculus forming a reticular substance.

B White Matter Consists of three pairs of funiculi (white columns) each consisting of fasciculi or nervous pathways

1 Funiculi.
   a. Dorsal funiculi Between dorsal gray columns and the median dorsal septum
   b Ventral funiculi Between ventral gray columns and the median ventral sulcus
   c. Lateral funiculi Between dorsal and ventral gray columns

2. White Commissure. Just below the gray commissure in the ventral funiculi, a horizontal band of fibres constitutes the ventral white commissure

3 Fibre Tracts. The nervous pathways (tracts) lie in three roughly defined zones
   a Proximal zone. Contains intersegmental fibres which both originate and terminate in spinal gray (Fasciculi proprii or ground bundles)
   b Peripheral zone. Contains the suprasegmental pathways ascending from cord to brain
   c. Intermediate zone. In the lateral and ventral funiculi an intermediate zone contains the pathways descending from brain to cord

4 Components The tracts are made up of fibres from three sources
   a Dorsal root ganglia Central processes of dorsal root ganglion cells make up the larger part of the dorsal funiculi and dorsolateral tract of Lissauer
   b Dorsal gray columns. The ascending pathways (except dorsal funiculi) and fasciculi proprii take origin in the gray column
   c. Brain The descending spinal tracts originate in various parts of the brain

5 Further analysis of fibre tracts is deferred until after consideration of the spinal nerve components

III THE SPINAL NERVES Thirty-one pairs A typical spinal nerve (T_{3} .) consists of several uniform parts

A Somatic Components. The major part of each nerve supplies the skeletal muscle, skin, and intermediate connective tissue

1 Dorsal Root and Ganglion The spinal ganglia constitute the afferent gray column The root contains all spinal afferent fibres The ganglion consists of a large number of large and small ganglion cells, each of whose single axon divides into a small central and larger peripheral process The former enter the spinal cord, the latter join the ventral root to form the nerve trunk

2. Ventral Root Contains the axons of the ventral and lateral gray column cells, which leave the cord in groups of filaments

3 Nerve Trunk. The union of dorsal afferent and ventral efferent roots produces a mixed trunk which after giving

innervation to the smooth (and cardiac) muscle of the viscera

b Visceral afferent fibres run from the viscera (et adnexa), through the sympathetic ganglia and white rami communicantes to reach the dorsal roots and ganglia, in which the ganglion cells lie, whence they enter the cord with the other afferent root fibres (It should be emphasized that the '*sympathetic*' is a motor system *by definition* and hence the afferent components of visceral nerves are *not* designated 'sympathetic')

c. Sympathetic preganglionics The splanchnic nerves proper contain largely preganglionics which have traversed the trunk ganglia without synapse to reach central unpaired prevertebral ganglia, whence postganglionics reach abdominal and pelvic viscera

5 The Pelvic Visceral Nerve consists of parasympathetic preganglionic fibres from the intermediolateral column (S_{2-4}), to ganglia in the pelvic viscera

C. Segmentation Initially each embryonic spinal nerve innervates the muscles and skin of one body segment or metamere

1 Muscular Nerve Segmentation The dorsal primary rami to the epaxial or true back muscles retain in the adult a clearly segmental pattern The hypaxial muscles (the appendicular and most of the trunk muscles) innervated by the ventral rami undergo complex development, and most of the ventral rami are involved in plexuses

2 Dermatomes The afferent nerves are distributed in a well defined segmental pattern, each nerve innervating a horizontal belt of skin, a 'dermatome' In plexuses the afferents from any one root may be distributed in several different nerves, yet the constituent root fibres reach their appropriate dermatome This is well illustrated by *Herpes zoster* a virus infection of the posterior roots resulting in a series of peripheral blisters strictly confined to the skin belt of the affected root level

3 Overlap Trunk dermatomes overlap to the extent that loss of a single root results in no appreciable anesthesia There is less overlap in appendicular dermatomes

D Nerve Root Components. A nerve is composed of several dif

ferent kinds of fibres The afferent fibres subserving each separate category of sense modality, and the efferent fibres to somatic and visceral muscles, are known as the components of a nerve

1 Afferent Components Nerve endings subserving cutaneous sense are described as *exteroceptive* those of muscle sense and deep pressure as *proprioceptive* and the visceral afferents as *interoceptive* The following is a summary of the chief afferent endings

   a Exteroceptive. Skin and subcutaneous tissue
      (1) Free endings Small myelinated and unmyelinated Subserve pain
      (2) Hair follicles Large myelinated Tactile sense
      (3) Encapsulated endings
         (a) Meissner's and Merkle's corpuscles. Large myelinated Tactile sense
         (b) Pacinian corpuscle. Large myelinated Pressure
         (c) Krause corpuscle. Small myelinated and unmyelinated Cold
         (d) Ruffini corpuscle. Small myelinated and unmyelinated Warmth

   b Proprioceptive. Muscle, tendon and joint capsule, mostly large myelinated fibres
      (1) Free endings
      (2) Pacinian corpuscles Pressure, movement
      (3) Muscle spindles and tendon organs of Golgi Active and passive stretch

   c. Interoceptive Viscera and mesenteries Many of these fibres traverse the sympathetic trunk and white rami
      (1) Free endings
      (2) Pacinian corpuscles

   d Arrangement In the dorsal root, the fibres of all of these components are intermingled In the cord, the several modalities become separated into more or less distinct ascending pathways

2. Efferent Components The ventral root contains all of the motor fibres to somatic muscle, visceral muscle, and glands

   a Somatic. The muscular nerves carry the motor fibres to the muscles, where each axon divides into many

terminals supplying a large number of muscle cells Each neurone and *its numerous* muscle cells constitute a *motor unit*

b Visceral The cutaneous nerves, muscular nerves and visceral nerves all carry sympathetic postganglionics from the sympathetic trunk ganglia The preganglionics are contained in the ventral roots

(1) Sympathetic Sympathetic preganglionics are found in the ventral roots from the first thoracic to the second or third lumbar level

(2) Parasympathetic (sacral division) Preganglionics are found in the second to fourth sacral roots, where they run to terminal ganglia in the pelvic viscera

(3) Vasodilators Stimualtion of dorsal roots results in peripheral vasodilatation The neurones are afferent type monopolar cells in the spinal ganglia

c. The spinal root of Cr XI will be considered with the cranial nerves

IV ROOT ENTRANCE ZONE The dorsal root filaments entering the dorsolateral sulcus divide into a small lateral and a large medial division

A Medial Division Mostly fibres of large diameter, which enter the dorsal funiculus close to the dorsal gray column Each fibre divides in Y fashion into a long ascending and a short descending process

1 Ascending Fibres These constitute the greater part of each dorsal funiculus, the fibres from each root being at first lateral, then becoming more medial as each new contribution at higher segments occupies the lateral portion of each funiculus Some fibres end in the spinal gray, and others reach the dorsal gray of the medulla In the cervical region the fibres of lumbosacral origin form the medial fasciculus gracilus (column of Gall), and the cervical fibres form the lateral fasciculus cuneatus (column of Burdach) They end in the nuclei gracilis and cuneatus in the medulla

2. Descending Fibres These shorter fibres course in two groups, the fasciculi septomarginalis and interfascicularis

3 Collaterals. The ascending and descending processes give off collaterals at various levels which enter the dorsal gray column By means of their synapses, pathways are provided for direct reflex response as well as connections to higher centers

B Lateral Division. This small division of the root consists of small myelinated and unmyelinated fibres They enter the dorsolateral tract (of Lissauer) between the apex of the dorsal gray and the dorsolateral sulcus Here each branches into a short ascending and descending process spanning but a segment or less of the cord It ends in the dorsal gray column, primarily in the substantia gelatinosa

V PATHWAYS OF THE SPINAL CORD The incoming root fibres carrying the various sense modalities end either directly in the dorsal gray column or send collaterals which synapse with cells therein

A Intrasegmental Firstly, connections are established with interneurones (internuncial cells) whose unmyelinated axons do not leave the central gray The interneurone system is more complex than the following simple categories indicate

1 Commissural Neurones send their axons across the midline to end in the opposite ventral gray column

2. Association Neurones end directly in the homolateral motor column

B Intersegmental. Secondly, connections are established with neurones whose usually myelinated axons leave the cnetral gray to course up or down the cord in the ground bundles (fasciculi proprii) These fibres, after a course of varying length re-enter the gray to end presumably in the motor columns

C. Suprasegmental Thirdly, connections are established with neurones whose axons run out into the peripheral zone of the funiculi to ascend in tracts to higher (suprasegmental) parts of the nervous system Most of these fibres cross in the ventral white commissure of the cord They may be thus classified

1 Cerebellar Afferents. Proprioceptive fibres enter the cord in the medial root divisions, and ascend to the medulla in the dorsal funiculi Collaterals and the descending branches of

these end on cells in the dorsal gray column, whose axon ascend to the cerebellar cortex in two tracts

a. Ventral spinocerebellar tract. Occupies the ventral peripheral portion of the lateral funiculus It contains fibres from both contra and homo-lateral dorsal gray, primarily the lumbosacral region, to the anterior cerebellar cortex

b Dorsal spinocerebellar tract. Occupies the peripheral portion of the lateral funiculus dorsal to the preceding Large cells in the *dorsal nucleus of Clarke* send their axons to tract of both same and opposite sides of cord in upper lumbar and thoracic regions, to posterior (and anterior) cerebellar vermis (The cerebellar pathway for fibres of cervical root origin is mediated by the lateral cuneate nucleus in the medulla)

2. Midbrain Afferents. The spinotectal tracts occupy the ventral peripheral portion of the lateral funiculus The axons arise from cells in the dorsal gray, cross in the white commissure, and ascend to the tectum (corpora quadrigemina) of the midbrain

3 Forebrain Afferents. The afferent pathways reaching the forebrain synapse in the posterior ventral thalamic nucleus, from which tertiary neurones run to the postcentral cortex

a. Dorsal funiculus. The proprioceptive fibres entering and ascending as the fasciculi gracilis and cuneatus constitute a second proprioceptive path (the first being the spinocerebellar fasciculi) From the nuclei gracilis and cuneatus in the medulla, the pathway crosses, ascends to thalamus and cortex This pathway carries not only proprioceptors, but also vibratory' sense, two-point sensibility, and discriminative touch

b Ventral spinothalamic tract. Exteroceptive fibres mediating touch and pressure enter the dorsal funiculus through the medial root, branch into ascending and descending processes These pass up and down the cord for many segments, giving off collaterals to the dorsal gray before terminating therein Secondary neurones cross in the ventral white commissure and ascend in the ventral regions of each ventral funiculus to the

thalamus, whence tertiary neurones lead to the cortex

c. Lateral spinothalamic tract. The exteroceptive fibres mediating pain and temperature enter the tract of Lissauer in the lateral root, where they terminate, within a segment or two, primarily in the substantia gelatinosa Secondary neurones cross in the ventral white commissure, and ascend in the ventral peripheral portion of the lateral funiculus to the thalamus The ventral spinocerebellar, lateral spinothalamic, and spinotectal tracts together constitute *Gowers tract*

4 Clinical Examples The results of disease processes illustrate the anatomy of the cord

a. Syringomyelia. The thalamic afferents decussate at three levels the pain temperature path crosses at once, the touch pressure path crosses for a considerable distance above the entrance level, and the proprioceptive path decussates in the medulla Syringomyelia, characterized by cavity formation in the central gray commissure, obstructs the ventral white commissure. As a result the patient is analgesic at the affected level but tactile sensation may be unaffected or reduced only at a much lower spinal level Thus, fibres crossing at the fifth thoracic level consist of pain fibres from about the sixth thoracic dermatome, but touch fibres from much lower segments

b Tabes dorsalis. Progressive degeneration of the dorsal fasciculi and roots results in the following

(1) Reduced muscular tone and deep reflexes. Partly because of loss of intra- and intersegmental circuits mediating myotatic reflexes.

(2) Muscular incoordination. Through loss of proprioceptive paths to cerebellum and forebrain

(3) Loss of discriminative touch. (Vibratory and two-point sensibility) Loss of dorsal fasciculi

D Efferent Pathways. The intermediate zone of both lateral and ventral funiculi carry suprasegmental upper motor fibres from higher neural levels to segmental lower motor neurones There may or may not be an interneurone interpolated in the central gray between the upper and lower motor neurones

1 Cerebellar Efferents No efferents reach the cord directly from the cerebellum Several pathways carry fibres from nuclei associated with the cerebellum
   a Rubrospinal tract A small fascicle of fibres from the posterior (magnocellular) part of the red nucleus travel in the central part of the lateral funiculus
   b Vestibulospinal tracts Fibres from the lateral vestibular (Deiter s) nucleus travel in the lateral funiculus, and others from the medial vestibular (Schwalbe s) nucleus travel in the ventral funiculus
2 Midbrain Efferents Tectospinal fibres arising in the corpora quadrigemina (primarily the superior colliculi) descend in ventral funiculus
3 Forebrain Efferents Fibres originating in pyramidal cells (including the giant cells of Betz) of the precentral gyrus reach the cord in two pathways
   a Lateral corticospinal tract The larger portion of the pyramids emerging from the pons decussate to form the lateral or crossed pyramidal tract, occupying a large area of each lateral funiculus above the rubrospinal tract and medial to the dorsal spinocerebellar tract Some ipselateral fibres are also present (Below the thoracic region, the lateral corticospinal tract is peripheral, because the dorsal spinocerebellar tract occurs only in the thoracic and cervical regions)
   b Ventral corticospinal tract The smaller portion of the pyramids continue directly into the ventral funiculus of each side where they are located close to the median sulcus Most fibres cross to the other side before synapsing with motor column cells
   c Reticulospinal tract Reticular nuclei, including the red nucleus and substantia nigra, receive fibres from the cortex, the corpora striata and other basal ganglia, and send axons into the cord

E. Brown Sequard Syndrome. Hemisection of the cord produces the following
   1 Clinical Picture.
      a Paralysis of voluntary movement below injury on same side of body The upper motor neurones are severed,

leaving the lower motor neurones under purely segmental control, with resulting spastic paralysis (increased deep reflexes due to extrapyramidal tract involvement)

b Increased blood flow Loss of tone in vasoconstrictors

c. Loss of proprioception on same side, below injury

d Loss of pain temperature sense, on opposite side below injury

2 Histological Picture. All fibres separated from their cell bodies degenerate

a Ascending degeneration The ascending pathways degenerate above the injury

b Descending degeneration The efferent pathways below the injury degenerate, as well as descending branches of the entering posterior root fibres

F Integrative Levels In summary, the peripheral afferent and efferent neurones may be said to be integrated at two major levels

1 Segmental The incoming root fibres connect with intra and intersegmental neurones in the dorsal gray columns, which provide for immediate and relatively simple reflex response Examples are the myotatic, and scratch reflexes

2 Suprasegmental The afferent root fibres also connect with pathways reaching higher centers, where various integrations take place in many and parallel circuits The various upper motor neurones converge on the segmental motor neurones, and the latter constitute a final common path to the muscles

3 The embryonic alar (association) plate and its derivatives constitute the integrative division of the nervous system

4 The neural crest (receptor plate) and basal (motor) plate give rise to the afferent and efferent divisions

III

BRAIN

I POSITION The brain is contained within the cranial cavity of the skull Dorsally it occupies the rounded calvarium, ventrally the three cranial fossae, each of which consists of a medial and two lateral portions

A. Posterior Fossa. Contains the medulla, pons and cerebellum

B Middle Fossa. Contains the midbrain and thalamus, and laterally the temporal lobes

C. Anterior Fossa. Frontal and olfactory lobes

D Calvarium. The dorsal parts of the cerebral hemispheres

II MENINGES The brain is separated from the skull by three meninges, the dura, pia mater, and arachnoid

A. The Dura is a thick fibrous membrane, which, unlike its relations around the cord, is closely applied to the interior of the skull, and serves as its periosteum Two layers can be demonstrated, between which are contained the cerebral venous sinuses The outer layer is adherent to the skull, the inner layer is infolded to form, as follows

1 Falx Cerebri, a sagittal septum separating (dorsally) the cerebral hemispheres

2. Tentorium Cerebelli, the roof of the posterior cranial fossa, a horizontal septum separating cerebrum from cerebellum, and notched to allow passage of the midbrain

3 Falx Cerebelli, a shallow infolding below the tentorium

4 Diaphragma Sellae, a washer shaped membrane separating the pituitary body from the hypothalamus, except for passage of the pituitary stalk

B The Pia Mater A thin investment closely adherent to the entire external surface of the brain, dipping deep into the sulci and enveloping the entrance portions of the cerebral blood vessels

C. Arachnoid. Close beneath the dura, and separated, by the epi

and nodose ganglia of the ninth and tenth lie outside of the skull The nerves leave the brain in a ventral and lateral series

A. Ventral Series Somatic muscular nerves The third, fourth, sixth and twelfth nerves

B Lateral Series Afferent fibres, and visceral efferent (Exception visceral efferent constrictor pupillae fibres leave in the ventral series, in the third nerve) The fifth, seventh, ninth, tenth and eleventh leave in the lateral series, and the eighth more dorsally (Note the nerves to the striated visceral muscles of the branchial arches are included in the visceral efferent group)

C Proprioceptive (afferent) fibres may be included in some of the ventral somatic roots (Small ganglia occur on oculomotor nerve branches)

V THE MEDULLA OBLONGATA is continuous with and alike the cord at its lower end Redisposition of old, and addition of new parts produces considerable change in its upper parts It is a truncated cone one and one half inches long, and contains in its upper half the lower part of the fourth ventricle

A Sulci Most of the fissures seen in the cord can be recognized in the medulla

1 The Dorsomedian Sulcus Half way up the medulla, this sulcus becomes shallow and spreads apart as the walls of the ventricle diverge

2 The Dorsolateral Sulcus spreads more laterally with the opening of the ventricular walls Rootlets of the ninth, tenth and eleventh nerves enter and leave near this sulcus

3 The Ventrolateral Sulcus separating the olives from the pyramids, marks the line of emergence of the ventral root series

4 The Median Ventral Sulcus is partially obscured by the *decussation of the pyramids* in its lower part

5 The Dorso-intermediate Sulcus lies between the clava and cuneate tubercle

B Areas of the Medulla The sulci demarcate three paired areas continuous with but differing considerably from the funiculi of the cord

1 Dorsal Area Includes the clava and, more laterally, the cuneate tubercle, produced by the underlying nuclei gracilis and cuneatus Above the cuneate tubercle, the diverging walls of the ventricle are formed by the restiform bodies The posterior medullary velum roofs the ventricle between them The dorsal and ventral cochlear nuclei partially encircle the restiform body at its upper end

2. Lateral Area Contains the emerging rootlets of the spinal accessory nerve (as does the lateral funiculus of the upper cervical cord) and rootlets of vagus and glossopharyngeal nerves Between these rootlets and the dorsolateral sulcus lies the tuberculum cinereum formed by the underlying substantia gelatinosa and spinal root of the fifth nerve. More ventrally is the swelling of the superior olive.

3 Ventral Area The upper portion is occupied by the pyramids which contains the corticospinal tracts covered with a thin layer of ventral external arcuate fibres and the arcuate nuclei In the lower medulla the decussation of corticospinal tracts takes place

4 Rhomboid Fossa Between the upper half of dorsal areas lies the ventricular floor, to be considered below

VI PONS Includes the pontine tegmentum and pons basilaris

A The Tegmentum (pars dorsalis pontis) is continuous with the medulla, and of comparable structure It is covered laterally and ventrally by the pons basilaris At the lower end lies the dorsal cochlear nucleus, and above, the superior cerebellar arms (brachia conjunctiva) form converging lateral walls of the ventricle Between them the anterior medullary velum roofs the narrowing ventricle

B Pars Basilaris Pontis A mass of nuclei and fibres forming a cerebrocerebellar pathway which covers both lateral and ventral parts of the tegmentum To this run the cortico-pontine tracts, and through it the corticospinal tracts

C. Internal Ventricular Surface To be considered below

D Nerves. The abducens nerve emerges ventrally between the pons and medulla The trigeminal nerve emerges on the anterior lateral surface of the pons

VII THE FOURTH VENTRICLE is a large rhomboid space continuous with the spinal canal below and the cerebral aqueduct above.

A *The Floor* consists of the diamond shaped ventricular surfaces of the medulla and pons A longitudinal sulcus in the midline indicates the median raphe (embryonic floor plate) More laterally the shallow sulcus limitans separates each half of the floor into two columns Medially, on each side of the longitudinal sulcus lie the original basal plates of the embryo Laterally lie the two alar plates

1 Basal Plate Area At the lower end is the medial hypoglossal trigone and lateral ala cinerea (dorsal vagus nucleus) Higher up in the pontine portion lies the colliculus of the facial nerve and abducens nucleus

2 Alar Plate Area The central portion is largely occupied by the large vestibular nuclei across which run the medullary striae At the widest part lie the dorsal cochlear nuclei, and the locus caeruleus lies at the upper end

B Lateral Walls

1 *The* Inferior diverging walls on each side are formed by the clava, the cuneate tubercle, and the restiform body

2 *The* Superior converging walls are formed by the inner and superior cerebellar arms

C. Roof The posterior medullary velum forms the lower roof, the cerebellum the central portion, and the anterior medullary velum the upper

D Choroid Plexus The posterior medullary velum contains capillary beds invaginated into the ventricle in the form of a T At the widest part of the ventricle, the foramina of Luschka open into the subarachnoid space, allowing passage of cerebrospinal fluid The plexuses protrude through the foramina A foramen of Magendie may occur near the lower apex of the roof

VIII MIDBRAIN Consists of the dorsal corpora quadrigemina, a central tegmental portion, and the paired cerebral peduncles

A Corpora Quadrigemina The paired superior and inferior colliculi are connected to the lateral and medial geniculate bodies of the thalamus by the superior and inferior quadrigeminal arms

B Tegmentum Continuous with pontine tegmentum Contains

the nuclei of the oculomotor and trochlear nerves, and the cerebral aqueduct

C. Basis Pedunculi. The cerebral peduncles consist of a tegmental portion, and a basis pedunculi which is truly cerebral Above, as the peduncles emerge from the forebrain, they are encircled by the optic tracts, and below they enter the pars basilaris pontis

D Nerves. The oculomotor nerves emerge ventrally in the interpeduncular fossa, the trochlear dorsally after crossing above the aqueduct

IV

MEDULLA

I GENERAL ARRANGEMENT The medulla is composed of white and gray columns continuous with but differing from those of the cord

A Gray Columns. These are dorsally placed and form the floor of the lower half of the fourth ventricle. The deeper gray matter is largely reticular substance, while close to the ventricle lies the central gray The medial basal plate region contains the efferent nuclei of the cranial nerves The lateral alar plate forms the association nuclei in which the afferent nerve roots terminate The association nuclei include interneurone systems converging on the motor nuclei (segmental level) and also secondary ascending pathways to higher centers (suprasegmental level)

B White Columns. The lateral and ventral portions of the medulla are formed by the white columns They contain the pathways connecting the medulla and cord with cerebellum, mid brain and forebrain

C. Secondary Gray Masses (formed by ventral migration of alar plate cells) occupy deep portions of the white columns

D Reticular Substance. Much of the central portion of the medulla is formed from an intermixture of gray and white substance The nuclear material occupies much of the basal plate area, although mostly derived from the alar plate Through the region run many large myelinated fibres, transverse, arcuate, and longitudinal

E. Organization In general, the medulla may be conveniently divided into a segmental level, consisting of the efferent nuclei, and afferent ganglia with their nerve fibres and central connectives (interneurones), and a suprasegmental level consisting of their connections with the cerebellum, midbrain, and forebrain

II SEGMENTAL LEVEL. Includes the central and peripheral portions of the cranial nerves, the efferent nuclei, the afferent ganglia, and their internuncial connections

A The Efferent Gray Column The efferent nerve nuclei are situated in the original basal plate, and may be embedded in either central gray or reticular substance.

1 The Hypoglossal Nucleus is a long column of large multipolar neurones, lying dorsally in the medial (somatic) column close to the median raphe, extending throughout the lower two-thirds of the medulla Its efferent fibres emerge as a series of rootlets between olives and pyramids, to form the hypoglossal nerve supplying the somatic tongue muscles

2 The Ventral Vagus (Ambiguus) Nucleus is a thin column of large neurones in the lateral (visceral) motor column deep in the reticular gray, approximately coextensive with the hypoglossal nucleus Its fibres run first dorsal then lateral to emerge near the dorsolateral sulcus as a series of filaments, which are included in the motor portions of the glossopharyngeal, vagus, and bulbar accessory nerve. They supply the striated visceral muscles of larynx and pharynx.

3 The Dorsal Vagus Nucleus is a column of small (visceral motor) cells in the central gray, lateral to and partially coextensive with the hypoglossal nucleus Its small finely myelinated fibres course lateralward and are joined by ventral vagus fibres They are parasympathetic preganglionic fibres to the terminal ganglia of the vagus, in thoracic and upper abdominal viscera

4 The Inferior Salivatory Nucleus is located laterally in the basal plate The actual neurones have not been recognized. It supplies parasympathetic preganglionic fibres to the otic ganglion (by way of glossopharyngeal root and Jacobson s tympanic nerve)

B The Afferent Gray Column consists of the afferent ganglia located outside of the central nervous system Their several components will be considered with the cranial nerves Their central axons enter the medulla in the lateral roots of the vagus and glossopharyngeal nerves where their ascending and descending branches effect collateral and terminal synapses with neurones of the association column (terminal nuclei)

III SUPRASEGMENTAL LEVEL. This includes the association nuclei (in which terminate the afferent nerve fibres) with their ascending fibre systems, and the descending systems from higher centers to the motor nuclei

A Association Gray Column The terminal nuclei of the afferent nerves are situated in and are derived from the embryonic alar plate Each nucleus is closely associated with a root composed of ascending or descending branches of the afferent nerve fibres The column corresponds to and is continuous with the dorsal gray column ('dorsal horn') of the cord

1 The Nucleus Gracilis is a column of medium sized neurones in the dorsal funiculus of the lower medulla It receives the terminals of the fasciculus gracilis

2 The Nucleus Cuneatus consists of a thick column, similar, but lateral and superior to the nucleus gracilis It receives the terminals of the cuneate fasciculus

3 The Lateral Cuneate Nucleus is a small aggregate of large neurones lateral to the upper portion of cuneate nucleus It corresponds to Clarke s nucleus of the thoracic cord, and receives proprioceptive afferents (collaterals?) from cervical nerves

4 The Spinal Trigeminal Nucleus consists of substantia gelatinosa, continuous with that of cord, and extends throughout the medulla deeply lateral in the alar plate Receives the descending branches of most trigeminal afferents (the spinal trigeminal root) as well as small contributions from Cr VII, IX, and X (Arnold s auricular nerve)

5 The Spinal Vestibular Nucleus is located in the upper medulla, in the dorsolateral part of the alar plate region It receives the spinal vestibular root, consisting of small bundles of descending vestibular nerve fibres

6 The Solitary Nucleus consists of a thin column of gelatinous substance deep in medial portion of alar plate region, parallel to and approximately coextensive with the hypoglossal nucleus Receives the tractus solitarius containing visceral afferent root fibres (including taste) from the facial, glossopharyngeal, and vagus nerves

B Secondary Nuclei The olivary, arcuate and lateral reticular nuclei are not directly related to the afferent root fibres, and

(5) Reticulocerebellar fibres From lateral reticular nucleus of the same side. The above five tracts are contained in the restiform body

(6) Ventral spinocerebellar tract. This does not join the restiform body, but runs through the lateral white area, dorsal to the olives, and into the pons

(7) Arcuocerebellar fibres Probably ascend in the median raphe and cross the ventricular floor as medullary striae.

b To the midbrain The spinotectal pathway runs through the lateral white area dorsal to the olives Spino- and bulbo-tectal pathways are little known

c. To the forebrain.

(1) Medial fillet. A large group of fibres from the gracilis and cuneate nuclei course ventrally and medially as internal arcuate fibres They cross the median raphe and turn abruptly forward, forming a paired vertical column, *the medial fillet,* ascending to the thalamus This is the second step of the proprioceptive path to the forebrain

(2) Ventral spinothalamic tract. Continuous from ventral funiculus of cord, this tactile pathway may be associated with the medial fillet

(3) Lateral spinothalamic tract. The pain and temperature pathway lies in the lateral area dorsal to the olive.

(4) Trigeminothalamic tract. Fibres from the spinal trigeminal nucleus cross the median raphe and probably ascend near the opposite lateral spinothalamic tract.

(5) Solitariothalamic tract. Secondary afferents from the nucleus solitarius, including the taste fibres, to the thalamus The location of the pathway is unknown, but the taste fibres probably end in the medial posterior ventral nucleus of the thalamus

2. Efferent Pathways.

a. From the cerebellum. The cerebellum is only indirectly represented in the efferent systems of the medulla Ef

ferent pathways with secondary cerebellar connections include

(1) Vestibulospinal tract. These fibres form a dispersed group deep in the medulla dorsal to the olive

(2) The medial longitudinal bundle lies close to the midline, ventromedian to the hypoglossal nucleus and continues into the ventral funiculus of the cord

(3) Rubrospinal tract. A small tract, deep in the lateral white area, dorsal to the olive

(4) Reticulospinal tract Fibres from various reticular nuclei, probably including those with cerebellar connections

b From the midbrain The tectospinal tract lies near the median raphe, between the medial longitudinal bundle above and the medial fillet below The position of tectobulbar fibres is not known

c. From the forebrain

(1) The corticospinal tracts emerge from the pons as the *pyramids* in the ventral white area In the lower medulla the major portion of each tract crosses the median ventral sulcus and turns dorsal and lateral into the opposite lateral funiculus of the cord The pyramidal decussation is just below the decussation of the medial fillet The small uncrossed portion of pyramids continues as the ventral corticospinal tract

(2) Corticobulbar tracts Detached bundles of the cortical efferents course more dorsally and cross to reach the motor nuclei of the medulla

(3) Cortico-arcuate fibres. Fibres from the corticopontine system reach the arcuate nuclei

(4) Central tegmental (thalamo-olivary) tract. Contains several components, one of which ends extensively in the inferior olives (rubroreticulo-olivary tract)

V

PONS

I GENERAL ARRANGEMENT The pons is clearly separable into a dorsal tegmentum and a ventral pars basilaris pontis

A Tegmentum The pontine tegmentum is directly continuous with the medulla, and contains many of the same elements It is enclosed on ventral and lateral sides by the pons basilaris and pons arms, which partly obliterate the sulci and more obvious white areas seen in the medulla The tegmentum contains the gray efferent and association columns as well as white pathways The ventricular surfaces of these columns form the central gray, and the deeper portions the reticular gray It may be divided, as was the case in the medulla and cord, into two levels

1 The Segmental Level consists of the afferent ganglia and the efferent nuclei with their respective roots, between which interneurones are interpolated

2 The Suprasegmental Level consists of the major portion of the association column with its terminal nuclei, their afferent connections to higher centers, and the efferent tracts back to the motor column

B Pons Basilaris The pontine mass consists of large irregular nuclei, separated by transverse fibre tracts The nuclei receive direct corticopontine fibres which end in the homolateral pontine nuclei From these nuclei fibres cross forming horizontal bands which converge into the opposite pons arms to reach the cerebellar hemispheres The corticospinal tracts traverse the pars basilaris, and the trigeminal and abducens nerves also pass through it

II SEGMENTAL LEVEL

A The Motor Column The efferent nuclei lie in the basal plate area of the tegmentum, which for the most part consists of central gray and reticular substance

1 The Abducens Nucleus lies in the dorsal reticular area of

the lower pons Fibres from its large multipolar neurones pass ventralward to emerge at the ponto-medullary junction as the abducens nerve to the lateral rectus muscle Between the nucleus and the median raphe lie the facial nerve and the medial longitudinal bundle

2 The Facial Nucleus is a large aggregate of small nuclear masses lying in the deep lateral part of the basal plate in the lower pons Its fibres first run dorsomedially toward the facial nucleus, around which they curve as the internal genu of the facial nerve, and then ventrolateral between the basal and alar plates Emerging in the lateral root series, its fibres supply the striated visceral muscles of facial expression, and the stapedius

3 The Motor Trigeminal Nucleus is situated far lateral in the motor plate of the central pons Its efferent fibres course ventrolaterally to emerge in the lateral root series They form the portio minor trigemini which supplies the striated visceral muscles of mastication, and the tensor tympani

4 The Superior Salivatory Nucleus. The parasympathetic preganglionic fibres to the sphenopalatine and submaxillary ganglia arise from cells located in the lateral part of the motor column, and emerge in the nervus intermedius facialis

3 The Afferent Column Most of the afferent neurones are located as usual in peripheral ganglia (spiral organ of Corti, Scarpa s, geniculate, and gasserian ganglia) However, in the alar plate region of the upper pons and midbrain, there is a long thin column of afferent monopolar ganglion cells This *mesencephalic nucleus* of the trigeminal nerve consists of neurones whose fibres are carried in several parts, including alveolar branches of the fifth nerve Its terminal nucleus and secondary afferent connections are unknown Collaterals from the afferent fibres are said to reach the motor nuclei of the trigeminal and facial nerves The afferent fibres form a conspicuous tract (the mesencephalic root) alongside of the large ganglion cells

The terminal fibres of the afferent column (ganglia) end in the terminal nuclei of the association column They accompany terminal nuclei as spinal vestibular and spinal trigeminal roots

III. SUPRASEGMENTAL LEVEL.

A. The Association Column The terminal nuclei lie in the alar plate region forming the association column of the pons The association column of the upper pons is essentially lacking, as this part of the alar plate forms the embryonic cerebellum

1 The Trigeminal Nuclei.

a Spinal trigeminal nucleus Situated deeply lateral, it continues from the medulla half way up the pons passing dorsolateral to the facial nucleus, and ending lateral to the motor trigeminal nucleus It is accompanied by the spinal root of entering root fibres, composed mostly of small medullated fibres

b *Principal sensory nucleus* Situated lateral to the motor trigeminal nucleus, it is continuous with the upper end of the spinal nucleus The trigeminal nerve extends ventrolateral from the principal and motor nuclei, between which run the mesencephalic root fibers

c. The terminal nucleus of the mesencephalic root is unknown

2. The Vestibular Nuclei The vestibular portion of the auditory nerve enters a group of reticular nuclei termed the vestibular mass It is composed of four nuclei which are only partially terminal in nature They receive fibres from the cerebellum as well as from the vestibular nerve From the nuclei emerge not only afferent fibres to higher centers but also efferents to the motor nerve nuclei

a Medial vestibular nucleus (of Schwalbe) Situated in central gray in upper medulla and lower pons

b Lateral vestibular nucleus (of Deiter) Situated between the medial nucleus and the restiform body

c. Superior vestibular nucleus (of Bechterew) Continuous with and just above the lateral and medial nuclei

d. Inferior (spinal) vestibular nucleus. Situated in medulla described therewith The entering vestibular fibres bifurcate, the descending fibres forming the spinal vestibular root to the medial, lateral and inferior nuclei The ascending branches go not only to the superior nucleus but also form direct fibres to the cerebellum (flocculus)

3 Cochlear Nuclei The cochlear nuclei receive the spirally twisted cochlear nerve root, each fibre of which bifurcates into an ascending and a descending branch

a Dorsal cochlear nucleus (Tuberculum acousticum) Partially encircles the dorsolateral aspect of the restiform body at the ponto-medullary angle Receives the descending cochlear fibres

b Ventral cochlear nucleus Ventrolateral to the restiform body Receives the ascending branches of the cochlear root fibres

B Secondary Nuclei Several prominent nuclei do not primarily receive afferent nerve fibres The largest of these are the great pontine nuclei

1 Pontine Nuclei These irregular cell masses form a large part of the pontine mass They are cerebellar dependencies receiving the cortico-pontine tracts, and sending their fibres to the opposite cerebellar hemisphere

2. Superior Olives This small nucleus is situated deep in the reticular substance of the lower pons, ventromedial to the facial nucleus It receives fibres from the cochlear nuclei and perhaps some direct cochlear nerve fibres It sends fibres to the medial longitudinal bundle, abducens nucleus, and other motor nuclei

3 The Trapezoid Nuclei These small nuclei are closely associated with the superior olives

4 Nucleus of the Lateral Lemniscus Small nuclei along the lateral fillet

5 Nucleus Pigmentosis Pontis This column of pigment-containing cells lies closely medial to the mesencephalic trigeminal nucleus, with which it is sometimes confused It lies in the locus caeruleus Its connections are unknown

C. The White Columns The pathways, while in general continuous with those of the medulla have suffered some rearrangement in the pons They may be divided into afferent and efferent suprasegmental pathways

1 Afferent Tracts

a To the cerebellum The restiform body and pons arm reach the cerebellum by way of the pons

(1) Restiform body At the lower end of the pons

the restiform body turns dorsally, to become the inferior cerebellar arm Its components have been discussed with the medulla

(2) Juxtarestiform body Medial to the restiform body fibres from the superior and lateral vestibular nuclei circle dorsally to form an inner cerebellar arm, or vestibulo-cerebellar tract

(3) Ventral spinocerebellar tract Continues from the medulla, in deep pontine tegmentum, to middle pons, lying ventral to the facial and trigeminal nuclei It hooks dorsally around the central part of the trigeminal nerve, and externally around the superior cerebellar arm into the cerebellum

(4) Pons arm The large transverse bundles of the pons basilaris course dorsally into the pons arm to reach the cerebellar hemispheres

b To the midbrain

(1) The spinotectal tract Continues up through the pons in the ventrolateral tegmentum

(2) Bulbotectal tracts are practically unknown

(3) The lateral fillet has collateral connection with the midbrain tectum, but will be considered with the forebrain

c. To the forebrain

(1) The medial fillet Continues up through the pons between the tegmentum and the pons basilaris The base of each fillet, no longer between the inferior olives, spreads out lateral and dorsal, until each originally vertical fillet becomes horizontal

(2) The lateral spinothalamic tract, continuing in the same ventrolateral position as in medulla, becomes associated with the lateral part of the medial fillet as it twists horizontally

(3) The ventral spinothalamic tract is presumed to be associated with the medial fillet

(4) Trigeminothalamic fibres from the spinal trigeminal nucleus travel close to the opposite lateral spino-thalamic tract Those from the main trigeminal nucleus course in a more dorsal tegmental path

(5) The lateral fillet Second order neurones from the cochlear nuclei form the suprasegmental auditory pathway to the thalamus Some fibres from each cochlear nucleus cross ventral to the facial nuclei close to the superior olives, and turn forward toward the thalamus lateral to the medial fillet Other fibres join the lateral fillet *without crossing* Each fillet thus contains both the homolateral and contralateral fibres The auditory decussation passes horizontally through the longitudinal medial fillet, the combined structure forming the *trapezoid body* Collaterals (and terminals?) enter the superior olives, and trapezoid nuclei The superior olives send fibres to the medial longitudinal bundles and motor nuclei In the midbrain, collaterals from the medial fillets enter the inferior colliculi

2 Efferent Pathways.

a From the cerebellum There are both direct and indirect cerebellar tracts in the pons

(1) The superior cerebellar arms (Brachia conjunctiva) emerge from the cerebellum to form the lateral walls of the fourth ventricle in its upper pontine portion Across them is the anterior medullar velum forming the upper ventricular roof As the ventricle narrows into the cerebral aqueduct, the arms curve ventrally into the midbrain tegmentum They contain the dentate rubro-thalamic pathways

(2) Cerebellovestibular fibres enter the pons both medial and lateral (uncinate bundle) to the superior cerebellar arm

(3) The rubrospinal tract has secondary cerebellar connections It is a small tract in the ventrolateral tegmentum, ventral to the facial nucleus

(4) Medial longitudinal bundle. This tract lies close to the ventricular floor beside the median raphe It carries a variety of fibres, but many of them come from vestibular nuclei, and many end in the nuclei of the nerves to the external ocular muscles

Others descend into the cervical cord Among other components, each tract contains

(a) Descending fibres from the contralateral spinal vestibular nucleus

(b) Descending and ascending fibres from the contralateral medial vestibular nucleus

(c) Ascending fibres from the homolateral superior vestibular nucleus Fibres from the superior olives also run in this tract

(5) Vestibulospinal tracts descend from both lateral and medial vestibular nuclei

b From the midbrain Tectobulbar and tectospinal tracts descend through the tegmentum just ventral to the medial longitudinal bundle

c. From the forebrain

(1) The corticospinal tracts enter the pons from the cerebral peduncles They travel directly through the pons basilaris, giving off collaterals, and enter the medulla as the pyramids

(2) Corticobulbar tracts enter the pons between the medial fillets While most of their fibres cross to the contralateral motor nuclei, the facial nuclei representing the muscles of the upper face receive both contra and homolateral fibres

(3) The corticopontine tracts enter the pons basilaris as three bundles on each side The medial prefronto-pontine, the precentro-pontine and the lateral temporo pontine tracts reach the homolateral pontine nuclei, whence pontine fibres cross to the contralateral cerebellar hemispheres

(4) The thalamo-olivary tract (central tegmental bundle) occupies a conspicuous area in the reticular tegmentum, dorsal to the medial fillet

VI

MIDBRAIN

I GENERAL STRUCTURE The tegmentum of the midbrain is continuous with that of the pons The cerebral aqueduct is surrounded by central gray, and reticular gray is extensive more ventrally The substantia nigra separates the tegmentum from the basis pedunculi Dorsally lies the lamina quadrigemina

A The Basal Plate area is occupied by reticular gray and the lower half of the central gray The trochlear and oculomotor nuclei lie in or close to the latter The medial fillet, lateral fillet, and the dentate rubro-thalamic tracts run through, and the red nuclei lie within, the reticular substance

B The Alar Plate area includes the dorsal half of the central gray and the lamina quadrigemina

C The Segmental level is represented by the large afferent ganglion cells of the mesencephalic root of the trigeminal nerve, and the nuclei and fibres of trochlear and oculomotor nerves

II THE MOTOR COLUMN The trochlear and oculomotor nuclei represent the upper end of the efferent column which is continuous in cord but formed by separately spaced nuclei in the brain stem

A Trochlear Nucleus Small, compact in deep central gray close to the midline Its efferent fibres pass dorsally in the central gray and decussate at the upper extremity of the anterior medullary velum The fibres supply the superior oblique muscle

B Oculomotor Nucleus. This large wedge shaped column is composed of several cell groups lying in the central gray opposite the superior colliculus It is composed of a lateral somatic column on each side, and a medial nucleus in the midline A small-celled parasympathetic nucleus on each side lies dorsomedial to the somatic column Each oculomotor nerve receives fibres from each lateral nucleus as well as fibres from the median and visceral nuclei The fibres form separate bundles

which pass ventrally between or through the red nuclei and emerge between the peduncles

1 Somatic Nuclei. The several external ocular muscles are represented in order in the nuclei Levator palpabrae, Sup rectus, Medial rectus, Inf oblique and Inferior rectus The medial cell mass is the nucleus of Perlia, and is concerned with convergence while the lateral nuclei bring about conjugate movements Many fibres cross to enter the contralateral nerve

2 Visceral Nucleus The Edinger-Westphal nucleus contains the parasympathetic preganglionic neurones to the ciliary ganglion, each fibre running to one or two ganglion cells They are concerned with pupil constriction and lens accommodation

III. THE AFFERENT COLUMN The eye muscles contain many afferent endings, and apparently their fibres run through the oculomotor and trochlear nerves The ganglion cells have not been recognized, and their central connections are unknown The mesencephalic root of the trigeminal nerve contains large neurones on the lateral edge of the central gray as far up as the oculomotor nucleus Their connections are unknown

IV ASSOCIATION COLUMN Terminal nuclei are unrecognized above the middle pons Probably an internuncial system is interposed between the mesencephalic afferents and motor nuclei The alar plate is largely concerned with formation of the cerebellum and lamina quadrigemina in this region

V SECONDARY NUCLEI Several large nuclei are found in or close to the tegmentum, and the reticular substance is a widespread, diffuse nuclear mass

A The Reticular Substance forms a large central area in the mid brain and extends forward into the subthalamus The lower portion continuous with the pons contains the decussation of the dentate rubro-thalamic tracts The upper portion contains the red nuclei which project into the thalamus Many smaller nuclei are differentiated within it, including the tegmental and interpeduncular nuclei The reticular substance receives fibres

from the red nuclei and substantia nigra and forms reticulo bulbar and reticulo-spinal tracts

B The Red Nucleus is a large rounded cylinder consisting of several cell groups, situated in midbrain and thalamus Bundles of oculomotor fibres pass through it (as does also the habenulo-peduncular tract)

1 The Nucleus Ruber Magnocellularis is a small group of large neurones in the posterior part giving rise to the rubro-spinal tract

2 The Nucleus Ruber Parvicellularis consists of a large lateral part (origin of the rubroreticulo-olivary tract), and a medial part from which arise rubro-occulomotor fibres

C. The Substantia Nigra is an extensive lamina of gray matter separating the basis pedunculi from the tegmentum It contains several cell groups including large pigmented cells, and areas of small inconspicuous neurones Many of its fibres enter the reticular substance

D The Interstitial Nucleus of Cajal and Commissural Nucleus of Darkshevitch are situated close to the central gray, dorso-medial to the red nucleus Fibres from these nuclei enter the medial longitudinal bundle

VI THE CORPORA QUADRIGEMINA consist of paired superior and inferior colliculi, from which the brachia quadrigeminae extend to the thalamus The inferior colliculi are large rounded nuclei, and the superior colliculi consist of alternating gray and white layers Each has afferent and efferent connections with brain stem and cord The superior colliculus receives optic fibres, and the inferior receives collaterals of secondary cochlear neurones

VII WHITE COLUMNS Spinotectal tracts end, and tectospinal and rubrospinal tracts begin in the midbrain

A Afferent Tracts.

1 To the cerebellum The corticopontine tracts in the basis pedunculi are afferent to the cerebellum but will be considered with the forebrain efferents

2 To the midbrain Spinotectal and bulbotectal tracts reach the corpora quadrigemina In addition, the lateral fillets send collaterals to the inferior colliculus, while optic fibres

reach the superior colliculus through the superior quadrigeminal arm

3 To the forebrain The ascending thalamic tracts are situated in the reticular substance

a. The medial fillet courses on the ventral surface of the tegmentum It forms a broad horizontal band of longitudinal fibres in the lower midbrain but as it approaches the thalamus its lateral side turns dorsally Several other tracts are associated with the medial fillet

(1) The lateral spinothalamic tract runs with the lateral part of the fillet

(2) The ventral spinothalamic tract is presumed to course with the fillet

(3) The ventral trigeminothalamic tract contains fibres from the spinal trigeminal nucleus

b The dorsal trigeminothalamic pathway containing fibres from the main sensory nucleus lies close to the central gray

c. The lateral fillet courses on the lateral side of the reticular substance, and turns dorsally toward the inferior colliculus in which collaterals end The tract continues to the medial geniculate body of the thalamus in the inferior quadrigeminal arm

B Efferent Tracts

1 From the cerebellum.

a The brachium conjunctivum consisting primarily of the dentate rubro thalamic tract, curves ventrally from the pons into the midbrain, where the tract from each side decussates in the central tegmental region Its contralateral course runs directly to the red nucleus and thalamus, after giving off descending collaterals

b The rubrospinal tract is a small bundle from the large celled part of the red nucleus It crosses just ventral to the dentate rubral tract as the *ventral tegmental decussation of Forel* and courses in the ventrolateral tegmentum to the medulla and cord

c. The medial longitudinal bundle is a prominent tract just ventral to the trochlear and oculomotor nuclei, in

which many of its fibres end Others enter the tract from the interstitial and commissural nuclei

2. From the midbrain From the superior (and inferior ?) colliculi arise tectospinal fibres which course ventrally around the central gray, and cross dorsal to the dentate rubral tracts as the *dorsal tegmental decussation of Meynert* Tectobulbar fibres also leave the midbrain roof
3. From the forebrain The basis pedunculi contains the corticobulbar, spinal, and pontine tracts
   a The corticobulbar tracts lie in the medial, and dorsolateral parts of the peduncles Fibres cross to end in oculomotor and trochlear nuclei, while others descend into the pons between the medial fillets
   b The corticospinal tracts forms the central portion of each peduncle
   c. The prefronto-, precentro-, and temporo-pontine tracts lie in the medial, intermediate, and lateral parts of the peduncles
   d The thalamo-olivary tract appears in the reticular substance dorsal to the red nucleus and dentate rubral decussation, passing into the pontine tegmentum It receives many fibres from the red nucleus

VII

CRANIAL NERVES

I. ARRANGEMENT The cranial nerves differ considerably from the spinal nerves not only in form but also in components They emerge from the brain stem in a ventral and a lateral series

A. Ventral Series. The third, fourth, sixth and twelfth nerves leave the neural axis nearly in line with the ventral spinal root series, to which they are somewhat similar They innervate (motor and proprioceptive fibres) the somatic muscles of the head The oculomotor nerve also carries preganglionic parasympathetic fibres to the ciliary ganglion

B Lateral Series. The fifth, seventh, ninth, tenth, and eleventh nerves emerge laterally nearly in line with the dorsal roots of the cord They represent the nerves of the embryonic branchial arches, innervating the striated visceral muscles of each arch and the epithelium of the visceral pouches, and also the skin of the face. The musculature of the arches includes the muscles of mastication (first arch, trigeminal nerve), of facial expression (second arch, facial nerve), upper pharyngeal constrictors and stylopharyngeus (third arch, glossopharyngeal nerve), and laryngopharyngeal muscles (fourth and fifth arches, vagus accessory nerve) The skin of the face is almost completely innervated by the trigeminal nerve The facial, glossopharyngeal and vagus share in the innervation of a part of the external ear

C. The Acoustic Nerve, consisting of cochlear and vestibular divisions, enters the brain stem dorsal to the lateral series

II. CRANIAL NERVE COMPONENTS The cranial nerves contain not only the four general components (afferent and efferent divisions of somatic and visceral categories) but also special visceral efferent and afferent and special somatic afferent.

A. The Seven Components may be listed as follows

1 Somatic Efferent — To somatic muscles

2. Special Visceral Efferent (Branchiomeric)	To striated visceral muscles of the branchial arches. These muscles develop from lateral plate mesoderm and surround the cranial end of the gut.
3. General Visceral Efferent	Preganglionic parasympathetic. To smooth and cardiac muscle, and glands.
4. General Somatic Afferent	Cutaneous fibres and proprioceptives from somatic muscle.
5. Special Somatic Afferent	Fibres from cochlear and vestibular organs. Also the optic nerve.
6. General Visceral Afferent	Pain and tactile fibres from visceral surfaces. (Also proprioceptives in branchiomeric muscles.)
7. Special Visceral Afferent	Taste fibres. (Also the olfactory nerve fibres.)

B. Summary of the Cranial Nerves. Although twelve cranial nerves are numbered, a thirteenth *Nervus Terminalis* is associated with the olfactory nerve.

I. Olfactory Nerve (and Nervus Terminalis). Special visceral afferent neurones in the nasal mucous membrane, enter the olfactory bulb.

II. Optic Nerve. Special somatic afferent neurones are situated in the retina. They are not homologous to other afferent neurones and the optic nerve itself is a tract of the brain.

III. Oculomotor Nerve.

a. Somatic efferent neurones from oculomotor nuclei including nucleus of Perlia to most of the extrinsic muscles of the eye.

b. General visceral efferent. Preganglionic parasympa

thetic fibres to ciliary ganglion from Edinger Westphal nucleus

c. General somatic afferent Proprioceptive fibres from extrinsic eye muscles Small ganglia lie on oculomotor nerve branches

IV Trochlear Nerve.

a Somatic efferent. From trochlear nucleus dorsally and across anterior medullary velum to contralateral superior oblique muscle

b General somatic afferent. Proprioceptive fibres from superior oblique muscle

V Trigeminal Nerve. Consists of a large afferent *Portio major* and a small efferent *Portio minor*

a Special visceral efferent. From motor nucleus of fifth nerve to mastication muscles and tensor tympani (In portio minor)

b General somatic afferent. Cutaneous fibres with cell bodies in the gasserian ganglion, distributed to the skin of the face through ophthalamic, maxillary and mandibular branches

c. General visceral afferent.

1 Proprioceptive fibres from the mastication muscles Their cell bodies are situated in the lower part of the mesencephalic trigeminal nucleus

2. *Fibres of general sense from anterior two-thirds of* the tongue Many fibres from the palate, teeth, and paranasal sinuses have cells of origin in the upper part of the mesencephalic nucleus

VI Abducens Nucleus.

a Somatic efferent. Fibres from abducens nucleus to the lateral rectus muscle

b General somatic afferent. Proprioceptive fibres from lateral rectus

VII. Facial Nerve. Includes the partially separate nervus intermedius

a Special visceral efferent. Fibres of the facial nucleus to the muscles of facial expression, and the stapedius

b General visceral efferent. Preganglionic parasympathetic fibres from the superior salivatory nucleus by

way of nervus intermedius to sphenopalatine and submaxillary ganglia

c. General somatic afferent. Cutaneous fibres from small part of the external ear, with cell bodies in geniculate ganglion

d General visceral afferent. Proprioceptive fibres from the facial muscles

e. Special visceral afferent. Taste fibres from anterior two-thirds of tongue by way of chord-tympani and nervus intermedius

VIII The Acoustic Nerve Special somatic afferent, consists of two divisions

a. Vestibular nerve. Fibres from cristae and maculae of the vestibular apparatus, bipolar cells in Scarpa s ganglion Fibres enter vestibular nuclei

b Cochlear nerve. The fibres from the bipolar cells of the spiral organ of Corti, in passing to the cochlear nuclei, take a spiral course, unwinding the cochlear spiral

IX. Glossopharyngeal Nerve.

a General visceral efferent neurones from inferior salivatory nuclei through the tympanic plexus Preganglionic parasympathetic to the otic ganglion

b Special visceral efferent neurones from ventral vagus (ambiguus) nucleus to stylopharyngeus muscle (possibly upper pharyngeal constrictors also)

c. General somatic afferent. A few fibres from external ear (Arnold s nerve) cells in superior ganglion end in spinal trigeminal nucleus (or nucleus solitarius ?)

d General visceral afferent. Fibres from posterior one third of tongue, and from upper pharyngeal plexus cells in the petrosal ganglion end in nucleus solitarius

e. Special visceral afferent. Taste fibres from posterior one third of tongue, cells in petrosal ganglion, end in nucleus solitarius

X. Vagus Nerve.

a General visceral efferent. Preganglionic parasympathetic fibres from dorsal vagus nucleus to terminal ganglia in thoracic and upper abdominal viscera

b Special visceral efferent Neurones from ventral vagus (ambiguus) nucleus to the striated visceral muscles of larynx and pharynx

c. General somatic afferent. A few fibres from external ear (Arnold s nerve), cells in superior ganglion, end in the spinal trigeminal nucleus (nucleus solitarius ?)

d. General visceral afferent Afferent fibres from larynx, pharynx, and thoracic and abdominal viscera, cells in nodose ganglion, end in nucleus solitarius

e. Special visceral afferent. Taste fibres from epiglottis, cells in nodose ganglion, end in nucleus solitarius

XI Spinal Accessory Nerve. Consists of bulbar and spinal roots

a General visceral efferent. Preganglionic parasympathetic neurones from dorsal vagus nucleus, join vagus by bulbar root.

b Special visceral efferent. Fibres from ventral vagus nucleus, join vagus in bulbar root Also spinal root

c. Special visceral efferent Neurones in motor column of upper cervical cord, form spinal root to sternocleido mastoid and trapezius muscles

XII Hypoglossal Nucleus Somatic efferent neurones from hypoglossal nuclei to the tongue muscles

III THE GRAY COLUMNS The cranial nerves take origin from two gray columns, the motor nuclei and the afferent ganglia Fibres from the latter end in the terminal nuclei of a third (association) column

A The Motor Column consists of the efferent nuclei They may be divided into a somatic series and a visceral series

1 The Somatic Nuclei form a series close to the median raphe They innervate the somitic' muscles from dorsal head mesoderm The oculomotor, trochlear, abducens and hypoglossal nuclei make up this medial column

2 The Visceral Nuclei are situated in the lateral part of the basal plate (Exceptions the Edinger-Westphal nucleus lies close to the oculomotor nucleus, and embryonically the facial nucleus is medial) They may be subdivided into special visceral nuclei whose fibres go to striated visceral

muscle, and general visceral going to cardiac muscle smooth muscle, and glands

a The special visceral or branchiomeric nuclei form a lateral series of large-celled nuclei, the trigeminal, facial and ventral vagus Their fibres run in the fifth, seventh ninth, tenth and eleventh nerves, to muscles derived from the lateral plate mesoderm which surround the anterior end of the digestive tract

b The general visceral motor nuclei send parasympathetic preganglionic fibres to the terminal ganglia of the vagus nerve as well as to the ciliary, sphenopalatine, submaxillary and otic ganglia They innervate the thoracic and upper abdominal viscera, the salivary glands and the constrictor pupilae

B Afferent Column The afferent ganglion cells lie for the most part in the cranial ganglia The mesencephalic nucleus of the trigeminal nerve lies in the upper pons and midbrain The olfactory cells lie in the nasal mucosa, and the optic neurones in retina The ganglia include the gasserian, geniculate Scarpa s spiral organ of Corti, the superior and petros ganglia of the ninth and the superior and nodose ganglia of the tenth nerves The components in the ganglia may be briefly summarized

1 Distribution

a The general cutaneous neurones are mostly in the gasserian ganglion A few are situated in the geniculate and the superior ganglia of the ninth and tenth nerves

b Proprioceptors. The situations of these neurones are not well known Some may be in the gasserian geniculate, and mesencephalic nuclei Others may be in the upper cervical spinal ganglia Small ganglia are located along branches of the oculomotor nerve

c. General visceral afferent. These include cells in the gasserian geniculate, petros and nodose ganglia

d Special visceral afferent The cells of the taste fibres lie in the geniculate and petros ganglia, a few in the nodose.

e Special somatic afferent. The cochlear neurones lie in the spiral organ of Corti, the vestibular in Scarpa's

ganglion They are bipolar neurones, the cell bodies covered by myelin sheaths

2. Embryology The cranial ganglia develop from several separate rudiments
   a The neural crest gives rise to general somatic afferent fibres
   b The auditory (dorsolateral) placode gives rise to the neurones of the organ of Corti and Scarpa s ganglion
   c. The epibranchial (ventrolateral) placodes give rise to visceral afferent neurones
   d The alar plate probably gives rise to the mesencephalic trigeminal nucleus
   e. The olfactory placode forms the olfactory neurones

C. Association Column The afferent fibres end in terminal nuclei of the association column The fibres *form* central *roots* which may accompany a nucleus for some distance before terminating Many fibres bifurcate into ascending and descending branches, with many collateral before terminating The terminal association nuclei form a medial visceral column, and a more lateral somatic column

1 Visceral Column This consists of the nucleus solitarius and possibly some of the reticular substance The visceral afferent fibres include taste, and general sensibility The former end in *the* upper, the *latter* in the *lower* part of the nucleus solitarius

2 Somatic Column The general somatic afferents end in the principal and spinal trigeminal nuclei The auditory nerve fibres end in vestibular and cochlear nuclei In addition, the dorsal white *columns* of the cord end in the medulla (nuclei of Gall and Burdach) The external cuneate nuclei receive collaterals of cervical proprioceptive afferents
   a Trigeminal nuclei The nuclear mass is continuous with the substantia gelatinosa of the cord Its enlarged upper end is the 'principal trigeminal nucleus just lateral to the motor nucleus Cutaneous fibres from the trigeminal (also a few from the seventh, ninth and tenth) nerve form the closely investing spinal root These fibres include three types
      (1) Fibres which divide into ascending branches to

the principal nucleus, and descending branches to the spinal nucleus

(2) Fibres of large diameters which end in the principal nucleus

(3) Fibres of small diameters which end in the spinal nucleus Considerable evidence indicates that pain and temperature fibres comprise the latter group, while touch and pressure fibres end in the principal nucleus In a cross-section of the spinal tract, ophthalmic fibres are ventrally, maxillary are medially, and mandibular fibres more dorsally placed

b Vestibular nuclei The vestibular fibres divide into ascending and descending branches

(1) Ascending fibres end in the superior vestibular nucleus (and in flocculus)

(2) Descending fibres end in lateral, medial, and spinal vestibular nuclei

c. Cochlear nuclei The auditory fibres also divide into ascending and descending branches

(1) Ascending fibres enter the ventral cochlear nucleus

(2) Descending fibres enter the dorsal cochlear nucleus The fibres from each part of the cochlea take a spiral course in the nerve to the same extent that each part of the cochlea is spiraled There is a point to point projection of the cochlea into the cochlear nuclei

VIII

THE CEREBELLUM

I ORGANIZATION The cerebellum is a suprasegmental structure overlying the pons and upper medulla It is formed from the alar plates which become folded during the pontine flexure The posterior part forms the flocculonodular lobe and is related to the vestibular nerves and nuclei The larger anterior part forms the corpus cerebelli and receives the spinocerebellar tracts In mammals, the cerebellar hemispheres form large lateral extensions of the corpus, and receive the cortico-ponto-cerebellar tracts The cerebellum consists of a much foliated cortex, a central white or medullary substance, and several basal nuclei It is an integrative center receiving afferent tracts from cord, brainstem, and cerebrum, and sending efferent projections (by means of the basal nuclei) to various effector systems

II FLOCCULONODULAR LOBE Transverse fissures divide the cerebellum into several lobes, each of which is subdivided into transverse lobules The *posterolateral* or *uvulonodular fissure* early separates the posterior flocculonodular lobe from the larger corpus cerebelli Consisting of the paired flocculi and median nodulus, it receives primarily vestibular root fibres, and is concerned with equilibration

III CORPUS CEREBELLI The principal part of the cerebellum is divided into anterior, middle and posterior lobes by the primary and prepyramidal fissures Each consists of many transverse lobules

A The Anterior Lobe comprises the small *lingula* close above the anterior medullary velum, and the larger *central* lobule and *culmen*

B The Middle Lobe is separated from the anterior lobe by the *primary fissure* It comprises the large hemispheres (*ansoparamedian lobules*) as well as the median lobules *simplex folium* and *tuber* The *prepyramidal fissure* separates the middle from the posterior lobe

C. The Posterior Lobe includes the median *pyramis* and *uvula* and their lateral extension, the *paraflocculus* The posterolateral fissure separates the posterior from the flocculonodular lobe

IV THE VERMIS The cerebellum is conveniently divided into a median vermis and lateral hemispheres Much of the vermis represents the older parts of the cerebellum In a phylogenetic sense, the flocculonodular lobe may be designated the *archicerebellum* the anterior and posterior lobes, the *paleocerebellum* and the middle lobe and hemispheres the *neocerebellum* These designations are based upon the disposition of the afferent and efferent tracts of the cerebellum, but there is much overlap and no sharp boundaries between them

V THE CORTEX This gray stratum forms the entire external layer of the cerebellum Beneath it lies the afferent and efferent tracts constituting the white or *medullary substance* In a sagittal section the cortex is seen to extend into all fissures and cover all folia Each lobule consists of a central medullary substance covered by cortex, the total pattern forming the tree like *arbor vitae* The cortex is formed from mantle layer cells which migrate across the marginal stratum to form an external gray layer The histology of the cortex is uniform throughout, consisting of three layers, the outer *plexiform* and inner *granular* laver, separated by a layer of *Purkinje* cells

A The Purkinje Cells are large, isolated, flask shaped neurones, oriented with their bases resting on the inner or granular layer
   1 The Axon of each arises from the base, acquires a myelin sheath, crosses the granule layer, and enters the medullary substance Most end in the basal cerebellar nuclei, others turn back to the plexiform layer as 'arcuate' fibres Axon collaterals may return to the molecular layer, to synapse with other Purkinje cells
   2. The Dendrites, one or two are thick and highly branched extending across the plexiform layer All branching is in a sagittal plane, the dendrites of each cell forming a laterally flattened 'tree'

B The Plexiform Layer contains extrinsic fibres as well as intrinsic neurones

1 The Purkinje Cell Dendrites are the most conspicuous feature Each forms a well separated individual tree

2 The Climbing Fibres are long thin axon terminals applied to the Purkinje dendrites, and closely following the branching

3 The Basket Cells are stellate or fusiform cells, with short bushy dendrites The axon runs in a *sagittal* plane, ending as a dense basket around the Purkinje cell bodies Small stellate cells occur in the outer part of the plexiform layer

4 The Axons of Granule Cells extend from the granular layer into the outer plexiform layer, branch in T fashion into two *transverse* fibres which end on a large number of Purkinje or basket cells

C The Granular Layer consists of densely packed small cells (granules) each of which has several short dendrites, and a long axon ascending into the plexiform layer The dendrites receive the axon terminals of *mossy fibres* whose short branched club shaped endings synapse with the spidery granule cell dendrites in 'protoplasmic islands' The axons of Purkinje cells also run through the granular layer x

D The Medullary Substance contains several fibre types

1 *The Purkinje Axons form the efferent projections* of the cortex The majority terminate in basal cerebellar nuclei

2. Arcuate Fibres are the axons of Purkinje cells which form short association paths to adjacent cerebellar lobules They probably end as climbing fibres on Purkinje dendrites

3 Cerebellar Afferent Fibres These are from many subcerebellar sources, they end as mossy fibres in the granular layer

VI BASAL CEREBELLAR NUCLEI These form a transverse row deep in the medullary substance close above the fourth ventricle They receive most of the efferent Purkinje cell projection, and in turn project into the brain stem and thalamus They consist of large and small multipolar neurones

A The Fastigial Nucleus The roof nucleus of each side is a rounded mass medially placed in the ventricular roof at the level of the superior vestibular nucleus It receives Purkinje

fibres from the medial parts of anterior and posterior lobes, fibres from the vestibular nuclei, and perhaps collaterals from spinocerebellar tracts

B The Intermediate Nuclei (Nucleus Interpositus) lie lateral to each fastigial nucleus The small globose and larger emboliform (paleodentate) nuclei receive Purkinje axons from the paleocerebellum, particularly the more lateral parts of the anterior lobe

C. The Dentate Nucleus is a large purse shaped crumpled plate, with hilus facing medial and anterior, placed lateral to the intermediate nuclei It receives the Purkinje axons of the neocerebellum, and also of the paraflocculus

VII CEREBELLAR PATHWAYS The afferent and efferent tracts are contained in the three pairs of cerebellar peduncles

A The Peduncles or cerebellar arms are large trunks containing a variety of separate tracts

1 The Inferior Arm (Corpus restiform) contains mostly afferent tracts, primarily to the paleocerebellum

2. The Middle Arm (Brachium pontis) consists almost entirely of the large crossed pontocerebellar tracts to the hemispheres

3 The Superior Arm (Brachium conjunctivum) contains the major efferent cerebellar projections

4 The Juxtarestiform Body is a medial part of the restiform body and contains the vestibular connections of the archicerebellum

B The Afferent Tracts end in roughly segregated areas of the cortex corresponding generally to the archi, paleo-, and neocerebellar divisions

1 To the Flocculonodular Lobe.

a Vestibular root fibres to cortex of flocculus and nodulus

b Vestibulocerebellar fibres from vestibular nuclei to flocculus, nodulus (and also to lingula and uvula of corpus cerebelli)

c. Vestibulofastigial fibres from vestibular nuclei to fastigial nuclei

2. To the Anterior and Posterior Lobes of corpus cerebelli

a Ventral spinocerebellar tract Curves around superior

arm to end enter the anterior lobe (Culmen and central lobule, few to lingula and L simplex)

b Dorsal spinocerebellar tract From restiform body it enters both anterior and posterior lobes (Most spinocerebellar fibres cross in the cord Direct fibres cross in the cerebellar commissure)

c. Dorsal external arcuate fibres Fibres from lateral cuneate nucleus enter restiform body

d *Ventral external arcuate fibres, from cuneate, gracilar* (and arcuate ?) nuclei, enter the restiform body

e. Paleo-olivo-cerebellar tract Internal arcuate fibres from the paleo (accessory) olives enter restiform body, and end in vermiform parts of both anterior and posterior lobes

f Reticulocerebellar tract Fibres mostly from the lateral reticular nuclei, course in restiform body

g Trigeminocerebellar fibres (direct root fibres as well as nucleo-cerebellar fibres), probably end in paleocerebellum

3 To the Middle Lobe and Hemispheres

a Pontocerebellar tracts The pontine nuclei receive tracts from association areas of frontal and temporal cortex and from the precentral gyrus, as well as collaterals from the corticobulbar and spinal systems Pontocerebellar fibres cross and form the pons arms to the opposite hemisphere

b Neo-olivo-cerebellar tract Internal arcuate fibres leave the principal olives, enter opposite restiform body and end in the hemisphere cortex There is a point to point projection of the olives into the cerebellar cortex

c. Reticulocerebellar fibres from various tegmental nuclei also reach the hemispheres

C. Efferent Cerebellar Pathways The cerebellar cortex projects upon the basal nuclei in a localized point to point manner The efferent tracts originate in the basal nuclei, with one exception

1 From the Flocculonodular Lobe.

a Angular bundle of Lowry Direct Purkinje cell axons in floccular peduncle to vestibular and reticular nuclei

b Fastigiobulbar tract. Some fastigiobulbar fibres may have a flocculonodular origin

2. From the Anterior and Posterior Lobes. Medial parts of anterior and posterior lobes project into the fastigial nuclei, more lateral parts into the intermediate nuclei

a Hook bundle (uncinate fasciculus) of Russell. Crossed and uncrossed fibres from fastigial nuclei run forward and around superior arm, end in vestibular and reticular nuclei

b Fastigiobulbar tract. Other fastigial fibres run directly to vestibular and reticular nuclei

c. Interpositorubral tract Fibres from the emboliform and globose nuclei course in the dorsal field of the brachium conjunctivum, decussate, enter the magnocellular part of the red nucleus, which in turn gives rise to the rubrospinal tract Collaterals from the interpositorubral tract may descend to bulbar nuclei

3 From the Middle Lobe and Cerebellar Hemispheres. The hemisphere cortex projects into most of the dentate nucleus

a Dentate rubro-thalamic tract The dentate fibres emerge from the hilus as a large bundle, course in the lower part of the brachium conjunctivum and decussate, whence some run directly to the lateral ventral thalamic nucleus, while others end in the parvicellular part of the red nucleus Dentate thalamic fibres course to the lateral ventral nucleus, whence the tract is relayed to the motor cortex Fibres from some parts of the dentate nucleus belong to the paleocerebellar division, and run to the magnocellular part of the red nucleus

VIII CEREBELLAR LOCALIZATON Although the cerebellar cortex is uniform throughout, the distribution of cerebellar pathways provides some basis for localization

A. Archicerebellum The flocculonodular lobe (and lingula and uvula) receives chiefly vestibular afferents Its efferent connections are with the vestibulospinal tracts and medial longitudinal bundle

B Paleocerebellum The anterior and posterior lobes receive

chiefly the proprioceptive tracts Their efferent connections are mostly by the interposito-rubro-spinal system

C. Neocerebellum. The middle lobe and hemispheres receive the large cortico ponto-cerebellar tracts They project back to the forebrain cortex ('motor' area) by the dentate thalamic system

IX

CORPORA QUADRIGEMINA

I QUADRIGEMINAL PLATE. The suprasegmental midbrain tectum is developed from the alar plates It is a laminated structure bearing two pairs of collicular eminences In birds and reptiles it forms the large optic lobes In man, the *superior colliculi* (optic lobes) are greatly reduced, and the paired *inferior colliculi* (auditory lobes) are added The superior colliculi are concerned with optic, and the inferior with auditory reflexes

II INFERIOR COLLICULI The auditory lobes are correlated in development with the spirally wound cochlea, and are homologous to the tori semicirculares of reptiles

A. Structure. They consist chiefly of a large nucleus on each side, surrounded by capsular fibres Each is connected with the homolateral medial geniculate nucleus (of the thalamus) by an *inferior quadrigeminal arm*

B Pathways. Auditory and tactile fibres are integrated in the inferior colliculi

1 Afferent Tracts

a. Lateral lemniscus. Collaterals and terminals from cochlear and superior olivary nuclei of both sides enter the inferior colliculus in the lateral fillet

b Spinotectal and bulbotectal tracts. Fibres from the lateral funiculi of cord and brainstem enter the colliculi by passing around the central gray

2. Efferent Tracts.

a Tectogeniculate. Many fibres enter the brachium of the inferior colliculus joining lateral fillet fibres to reach the medial geniculate nucleus

b Tectobulbar and tectospinal tracts. Consist of few fibres of small diameter

c. Acoustico-optic fibres run from inferior to superior colliculi

d Intercollicular fibres form a commissure between the inferior colliculi

III SUPERIOR COLLICULI The optic lobes are low rounded eminences surmounting the central gray The *superior quadrigeminal arm* connects each superior colliculus with the lateral geniculate body of the same side

A Structure. Each optic lobe consists of alternating white and gray layers

1 Superficial White Layer (Stratum zonale) A thin layer of small cortico-tectal fibres

2 Superficial Gray Layer Small and large nerve cells Some optic fibres end, and some tectospinal fibres originate here

3 Optic Layer Mostly optic tract fibres entering through brachium of the superior colliculus

4 Middle Gray Layer Cells of origin of tecto-bulbar and tectospinal tracts

5 Middle White Layer Entering spinotectal (and occipitotectal ?) fibres, also some tectospinal fibres

6 Deep Gray Layer Neurones of large size with axons entering tecto-bulbar and tectospinal tracts

7 Deep White Layer Made up of axons from the deep gray layer

8 Periventricular Layer Mixed gray and white substance Includes the large tectospinal fibres, sometimes intermingled with mesencephalic root fibres

B Pathways Optic and tactile fibres are integrated in the superior colliculi

1 Afferent Tracts

a Optic nerve fibres (some uncrossed) enter the optic layer from the superior quadrigeminal brachium and optic tract.

b Occipito-tectal fibres (?) from occipital cortex, through optic radiation and superior arm, into middle white layer

c. Acoustico-tectal fibres, from inferior colliculi

d Spinotectal and bulbotectal tracts, enter middle white layer

2. Efferent Tracts.
   a Tectobulbar tract. This includes fibres to the oculomotor nucleus, red nucleus, substantia nigra, and other bulbar nuclei
   b Tectospinal tract. Fibres cross in the dorsal tegmental decussation, enter lateral funiculus of cord, to the ventral motor column In addition a small medial tectospinal tract in the ventral femiculus runs to the upper thoracic part of the intermediolateral cell column This is a dilator pupilae pathway from the optic tectum
   c. Intercollicular fibres form commissure between the superior colliculi
   d Tectocerebellar fibres (in anterior medullary velum) may contain fibres from superior and inferior colliculi

IV PRETECTAL NUCLEUS This nucleus lies closely in front of and below the superior colliculus in man, but is pretectal in many lower forms It receives crossed and uncrossed optic nerve fibres and sends crossed and uncrossed fibres to the Edinger-Westphal (pupilo-constrictor) nuclei of the oculomotor nerve It mediates the pupillary light reflex, but not the pupillary reflex of accommodation

X

THALAMUS

I THE FOREBRAIN develops from the alar plate forming the anterior end of the neural tube, and consists of the thalamus and the paired cerebral hemispheres The thalamus surrounds the third ventricle and consists of the diencephalon and the medial terminal part of the telencephalon ending at the lamina terminalis The cerebral hemispheres contain the lateral ventricles and each consists of a highly elaborated pallium and a basal corpus striatum and olfactory lobe They are suprasegmental structures containing the highest integrative levels, and the hemispheres alone are larger than all the rest of the brain The *thalamus* is literally and structurally an 'anteroom' to the hemispheres

A Dorsally it forms the floor of the transverse cerebral fissure, and the floor (lamina affixa) of the body of the lateral ventricle

B Laterally it is related to the caudate nucleus above, and the internal capsule

C. Ventrally lies the midbrain tegmentum extending into the subthalamus

D Posteriorly the rounded pulvinar overlies the subjacent geniculate bodies

E Medially each ventricular wall is crossed by the hypothalamic sulcus running from the cerebral aqueduct to the opening (interventricular foramen of Munro) of each lateral ventricle Above the sulcus lies the dorsal thalamus, bridged by the massa intermedia and roofed by the tela choroidia with its paired invaginated choroid plexuses Below the sulcus lies the hypothalamus

II THE DORSAL THALAMUS consists of large nuclear groups separated by white laminae *Anterior medial, lateral* and *ventral* nuclei with their subdivisions, and the *centromedian* (*of Luys*), *pulvinar* and *geniculate* nuclei are thus delimited Other nuclei are situated in the ventricular gray (*midline nuclei*), or in the laminae

(*intralaminar nuclei*) They are divided into three groups based upon their connections, and upon phylogenetic grounds

A The Subcortical Nuclei are an old (archithalamic) group with intrathalamic but no cortical connections

1 The Midline Nuclei are ill-defined groups in the dorsal ventricular wall and intermediate mass, having hypothalamic and pretectal connections

2 The Intralaminar Nuclei have little known intrathalamic connections The larger *centromedian nucleus* has connections with the globus pallidus

3 The Anterior Ventral Nucleus Connections unknown

B The Cortical Relay Nuclei are a newer group which receive the large afferent pathways from cord and brainstem, and relay them to the projection areas of the cerebral cortex, from which they receive cortico-thalamic fibres

1 The Posterior Ventral Nucleus is divided into a small medial part (arcuate or semilunar nucleus) which receives the trigemino-thalamic tracts (and probably fibres from the nucleus solitarius, including taste), and a large lateral part receiving the medial fillet and spinothalamic tracts They project into the postcentral gyrus (areas 3, 1, 2) by means of the thalamic radiation in the internal capsule

2. The Medial Geniculate Nucleus receives the lateral (auditory) fillet, and projects into the temporal lobe (transverse gyrus of Heschl)

3 The Lateral Geniculate Nucleus, consisting of six nuclear layers separated by white laminae, receives most of the optic tract Crossed fibres end in laminae 1, 4 and 6, and direct fibres in 2, 3 and 5 It projects into the striate cortex (area 17) by the geniculocalcarine tract

4 The Anterior Nucleus (anterior tubercle) receives the mammillothalamic tract, and projects into the cingular gyrus aod paracentral lobule

5 The Lateral Ventral Nucleus receives the dentate thalamic tract from the cerebellar hemispheres, and projects into the precentral gyrus (areas 6 and 4) It has discrete topographical representation of leg, arm, and head from lateral to medial

C. The Association Nuclei are recent (neothalamic) nuclei closely

correlated with the large association cortex of primates They receive short connectives primarily from the relay nuclei, and project into frontal and parietal association cortex

1 The Medial (dorso-medial) Nucleus receives fibres from other thalamic nuclei, and from the frontal cortex A small magnocellular part sends fibres to the posterior hypothalamic nucleus, while the large parvicellular nucleus sends fibres to and receives fibres from the frontal association cortex (areas 9, 10 and 12)

2. The Dorsal Lateral Nucleus receives many fibres from the ventral nuclei, and a few from the medial fillet

3 The Posterior Lateral Nucleus receives fibres from ventral nuclei, and tectum, and sends fibres to the parietal cortex (areas 5 and 7)

4 The Pulvinar is a large posterior mass receiving fibres from other thalamic nuclei The medial part sends fibres into the cortex (area 22) near the auditory areas, while the inferior part sends fibres into the peristriate cortex (area 18) of the visual area

D The Thalamic Radiation consists of thalamocortical and corticothalamic fibres which run in four bundles, the ventral, frontal, parietal, and occipital thalamic stalks Most of them form parts of the *internal capsule* a large band of fibres running through the corpus striatum and forming a sheaf around the lenticular nucleus

III THE VISUAL SYSTEM includes the retina, and optic nerve with its central connections

A The Retina is a specialized part of the forebrain wall (isolated by the embryonic optic evagination), from which a large fibre tract, the optic nerve, runs to the thalamus It is a cup-shaped organ consisting of a light and color sensitive neuroepithelium, and two layers of neurones with interposed synaptic layers

1 The Neuroepithelium consists of light sensitive *rod* cells, and color sensitive *cones* Most of the retina has both types of cells, but the *fovea centralis* (point of acute vision in center of the yellow *macula lutea*) has cone cells only, and the *optic pedicle* (blind spot of the optic nerve exit) has neither

2. The Bipolar Cell layer consists of neurones, the dendrites of which receive the bases of the rods and cones, and their axons reach the ganglion cells *Polysynaptic* bipolars receive a number of 'rod-spherules and *monosynaptic* bipolars receive a single 'cone pedicle.'
3. The Ganglion Cell layer consists of large neurones, the dendrites of which receive the bipolar cell terminals Their naked axons form a fibrous layer on the vitreous surface of the retina, converging on the optic pedicle to form the optic nerve, where they acquire myelin sheaths

B The Retino-Geniculate Tract originates in the ganglion cells of the retina, and ends primarily in the lateral geniculate nucleus. It consists of three segments, the optic nerve, the chiasma, and the optic tract.

1 The Optic Nerve runs from the retina to the optic chiasma. A lesion of a nerve causes blindness in one eye.
2. The Optic Chiasma is in the floor of the hypothalamus. The fibres from the nasal half of each retina cross and join the fibres from the temporal half of the opposite eye, producing a complete crossing of the visual image. A lesion in the central chiasm (nasal fibres) produces bitemporal hemianopia Paired lateral chiasmatic lesions (temporal fibres) produce binasal hemianopia.
3 The Optic Tract runs from the chiasma around the cerebral peduncle, enters the lateral geniculate nucleus and terminates therein A small band of fibres passes medially into the superior collicular arm A lesion of the optic tract produces homonymous hemianopia (blindness of the opposite visual field) The tract also contains fibres (from the medial geniculate body ?) forming Gudden s commissure through the optic chiasma.

C. The Lateral Geniculate Nucleus consists of six nuclear laminae, separated by fibrous layers The crossed fibres (from the nasal retinal halves) end in the first (at hilus), fourth, and sixth layers The direct (temporal) fibres end in layers two, three, and five. The macular fibres end in the upper and central two-thirds, the peripheral retinal fibres in the medial and lateral sixths. There is approximately point to point projection of the macular cones into the lateral geniculate nucleus, but anatom-

ically the rod projection probably overlaps (because of the polysynaptic bipolar cells in the retina)

D The Geniculo-Calcarine Tract (optic radiation) originates in the lateral geniculate nucleus, enters the thalamic radiation (in the sublenticular part of internal capsule) The fibres pass anteriorly and laterally around the inferior and posterior ventricular horns in the external sagittal stratum They are distributed to the striate cortex (area 17) along the calcarine fissure, with spacial representation of like retinal halves on each side A lesion of the temporal detour along the inferior ventricular horn may result in quadrantic hemianopia (loss of one quadrant of the visual field)

IV THE EPITHALAMUS includes the pineal body, posterior commissure, habenular nuclei, and the thalamic medullary striae They lie dorso medially, close to the roof of the third ventricle

A The Pineal Body is a midline structure attached to the thalamic roof in front of the superior colliculi It is non nervous and in adult life calcium salts frequently deposit there The pineal stalk contains the pineal recess, in front of which is the habenular commissure, and below is the posterior commissure

B The Posterior Commussure is a prominent transverse band at the anterior end of the pretectal area It contains, among others, fibres from the nearby commissural nucleus of Darkshevitch

C. The Habenular Nucleus of each side is located in front of and lateral to the pineal body It is part of the olfactory system, and receives fibres from the medial forebrain bundle by way of the thalamic medullary striae. It sends fibres to the interpeduncular nucleus in the habenulo interpeduncular tract (retroflex bundle) which passes through the edge of the red nucleus

D The Striae Medullaris Thalami run along the dorso-medial border of the thalamus close to the attachment of the tela choroidea They run from the medial forebrain bundle to the habenular nucleus of each side, many decussating in the habenular commissure

V THE HYPOTHALAMUS includes the hypothalamic nuclei, and a group of structures lying below the hypothalamic sulcus close to the lower part of the third ventricle

A The Lamina Terminalis forms the anterior wall, above which lies the *anterior commissure* Ventrally lies the *optic chiasma,* with the *preoptic recess* in front, further back is the *infundibulum* with the attached ***hypophysis*** and the *tuber cinereum* The *mammillary bodies* are paired nuclear masses projecting below the hypothalamic floor The walls of the hypothalamus consist of ventricular gray containing groups of nuclei

B The Hypothalamic Nuclei are a phylogenetically old group which includes suprasegmental nuclei contributing to the integration of visceral functions They receive fibres from the cortex and subcortical thalamic nuclei as well as ascending visceral pathways Efferent fibres connect with the autonomic system The nuclei are arranged in three groups

1 The Anterior Group lies above the optic chiasma

a The paraventricular nucleus consists of closely packed large cells containing secretory colloidal material in the cytoplasm It sends fibres to the supraoptic nucleus, infundibulum, and medulla

b The supraoptic nucleus, situated above the lateral part of the chiasma, consists of closely packed cells with colloidal material From it runs the supraopticohypophyseal tract to the posterior lobe and pars intermedia of the hypophysis, and also to the posterior hypothalamic and tuber nuclei

2 The Middle Group (Pars Infundibularis) lies in the tuber cinereum

a The tuber nuclei are small celled clusters which receive fibres from the frontal cortex, and send fibres into the midbrain, and probably to the parasympathetic nuclei

b The dorsomedial and ventromedial hypothalamic nuclei consist of small cells which probably connect with parasympathetic nuclei of both sacral cord and medulla

c. The lateral hypothalamic area consists of small groups of large cells, which probably connect with the sympathetic intermediolateral cell column of the thoracic cord

3 The Posterior Group lies behind the infundibulum

a The posterior hypothalamic nucleus consists of closely packed small cells among which are many large rounded cells It receives the periventricular fibres from the large

celled part of the dorsomedial thalamic nucleus, which in turn receives fibres from the frontal cortex From the posterior nucleus efferent tracts descend in the medial longitudinal bundle to the sympathetic intermediolateral cell column of the thoracic cord

b Each mammillary body consists of a large medial and smaller lateral nuclei The medial nucleus receives the fornix, the projection of the hippocampal cortex From it runs the mammillothalamic tract to the anterior thalamic nucleus, which in turn projects to the gyrus cingulum

C The Fibre Tracts to and from the hypothalamic nuclei are little known, but clinical and physiological evidence indicates that the nuclei are primarily concerned with visceral functions Lesions of the hypothalamic nuclei result in emotional disturbances, 'sham rage, narcolepsy, and disruption of temperature regulation, as well as disturbances of water, fat and carbohydrate metabolism Electrical stimulation of the dorsomedial, ventromedial, and tuber nuclei result in parasympathetic responses, while that of the lateral hypothalamic area and posterior hypothalamic nucleus produce sympathetic effects The paraventricular nuclei are concerned with carbohydrate metabolism, and lesions of the supraoptic nuclei result in diabetes insipidus

VI THE SUBTHALAMUS The midbrain tegmentum continues into the diencephalon where it ends as a group of nuclei and reticular substance below the dorsal thalamus Ventrolaterally the basis pedunculi spreads out into the internal capsule, which separates the dorsal and subthalamus from the lenticular nucleus of the corpus striatum

A The Nuclei of the subthalamus include the anterior ends of the red nucleus and substantia nigra as well as intrinsic nuclei

1 The Subthalamic Nucleus (Corpus Luys) lies anterior and lateral to the red nucleus It is a biconvex lens-shaped nucleus placed horizontally above the substantia nigra

2 The Zona Incerta is a sheet of gray matter between the subthalamic nucleus below and the lateral nuclei of the thalamus above

3 Reticular Substance occurs among the above four nuclei

B The Tracts passing through the subthalamus include two thalamic afferent pathways as well as descending bundles

1 The Medial Fillet passes through reticular substance lateral to the red nucleus and ends in the posterior ventral nuclei of the thalamus

2. The Dentate rubro-thalamic system spreads out laterally in front of the medial fillet, and ends in the lateral ventral nucleus The medial part around the red nucleus is the tegmental field H of Forel, and the lateral part the field H_1 of Forel They lie medial and dorsal to the other parts of the subthalamus

3 The Lenticular Fascicle is a bundle of fibres from the globus pallidus of the striate body It crosses dorso-medially through the internal capsule and passes between the subthalamic nucleus and the zona incerta, constituting field H_2 of Forel

4 The Ansa Lenticularis is a tract from the globus pallidus which passes ventrally around the medial border of the internal capsule to enter the subthalamus

C. The Connections of the subthalamus are little understood There are connections with the *corpus striatum, which will be* considered with those of the latter

XI

CEREBRAL HEMISPHERES

I TOPOGRAPHY Each hemisphere presents three surfaces and three poles The basal surface occupies the anterior and middle cranial fossae, the dorsolateral surface lies against the calvarium, and the medial surface lies in the superior sagittal fissure. The anterior end of the hemisphere is the frontal pole, the posterior the occipital pole, and the inferior the temporal pole

A The Basal Surface consists of a frontal and a temporal part separated by the deep *lateral fissure*

1 The Frontal part presents the *orbital gyri* laterally, and medially the *gyrus rectus* the *olfactory sulcus,* and the narrow *olfactory lobe* The latter ends posteriorly in the *medial* and *lateral olfactory striae,* between which lies the *anterior perforated substance*

2 The Temporal part is divided into three longitudinal folds, the medial *hippocampal gyrus* with the hook shaped *uncus,* the *fusiform gyrus,* and laterally the *inferior temporal gyrus*

B The Dorsolateral Surface, large and rounded, is divided into numerous gyri by narrow fissures or sulci

1. The Lateral Fissure (of Sylvius) separates the inferior *temporal lobe* from the *frontal* and *parietal lobes* Deep within the fissure lies an area of cortex, the *insula of Reil*

2. The Central Sulcus (of Rolando) separates the *frontal lobe* from the *parietal lobe*

3 The Frontal Lobe presents the following gyri

a The anterior central (precentral) gyrus between the central and precentral sulci

b The superior, middle, and inferior frontal gyri separated by superior and inferior frontal sulci

c. The inferior frontal gyrus is divided into *orbital triangular* and *opercular* parts by the anterior horizontal and ascending rami of the lateral fissure

4 The Parietal Lobe.

a The posterior central (postcentral) gyrus lies between the central and postcentral sulci

b The superior parietal gyrus lies above the interparietal sulcus

c. The inferior parietal gyrus includes the supramarginal and angular gyri

5 The Occipital Lobe surrounds the occipital pole and is arbitrarily demarked from the parietal lobe by a line from the preoccipital notch to the parieto-occipital fissure

6 The Temporal Lobe presents the *superior middle* and *inferior temporal gyri* In the lateral fissure the superior gyrus is divided into transverse gyri including the *anterior transverse gyrus of Heschl*

7 The Insula of Reil is an area of cortex overgrown by the frontal and temporal operculae which meet at the lateral fissure It is divided into the *long gyrus* and the anterior *short gyri* by the sulcus centralis insulae Beneath the insular cortex lies a thin sheet of gray matter, the *claustrum*

C. The Medial Surface of each hemisphere lies in the superior sagittal fissure, the floor of which is formed by the *corpus callosum* The medial surface presents frontal, parietal, and occipital regions

1 The Frontal Region presents the *superior frontal gyrus* and the anterior half of the *cingular gyrus* separated by the *cingular sulcus* Below the genu of the corpus callosum lie the *parolfactory area* and *subcallosal gyrus*

2. The Parietal Region presents the superior end of the central sulcus with the *paracentral lobule* and *precuneus* below which lies the posterior half of the cingular gyrus

3 The Occipital Region presents the *cuneus* above which is the parieto-occipital fissure and below is the *calcarine fissure* and *lingula gyrus* The cingular gyrus extends as the fornicate isthmus connecting behind the corpus callosum with the hippocampus

4 The Indusium Griseum is a thin gray layer (supracallosal gyrus) on the dorsal surface of the corpus callosum

D The Corpus Callosum is a large interhemispheric commissure, beginning as the *rostrum* at the anterior commissure, arching

up and back as the *genu* and *corpus*, and ending in the rounded *splenium*

E The Fornix is the efferent projection of the hippocampus It arches up and back around the thalamus, is attached to the under surface of the splenium, and curves down anteriorly, entering the thalamus behind the anterior commissure to end in the mammillary body

1 The Septa Pellucida are thin sheets extending from each fornix to the genu and body of the corpus callosum They enclose a small space, the fifth ventricle

2. The Choroid Fissure is a cleft between the fornix and the thalamus The lateral wall of the fissure is closed by a choroid tela with choroid plexus extending into the lateral ventricle

F A Lateral Ventricle is contained in each hemisphere It is continuous with the third ventricle at the interventricular foramen, and lined throughout with ependyma It consists of a body and three horns

1 The Anterior Horn lies in front of the interventricular foramen, and is enclosed above and in front by the genu of the corpus callosum. The head of the caudate nucleus forms the ventrolateral wall, and the septum pellucidum the medial

2. The Body of the lateral ventricle lies beneath the corpus callosum, the septum pellucidum, fornix and choroid tela are medial, the affixed thalamic lamina is ventral, and the caudate nucleus lateral

a The choroid tela is a narrow band of pia-ependyma continuous at the posterior wall of the interventricular foramen with that of the third ventricle. Attached to the outer edge of the fornix and to the dorsal thalamus, it continues into the inferior horn as its medial wall It contains the choroid plexus of the lateral ventricle

b The lamina affixa is a layer of ependyma representing the wall of the hemisphere reflected from the caudate nucleus medially over the dorsal thalamus to the tela and fornix

3 The Inferior Horn extends into the temporal lobe, and ends ventral to the amygdala nucleus Above lies the tape

tum of the corpus callosum, below is the collateral emi nence, hippocampus, fimbria and fornix, and medially is the tela choroidea

4 The Posterior Horn is a narrow slit extending into the occipital lobe On its floor is the calcar avis, a prominence formed by the calcarine fissure It is roofed by the tapetum of the corpus callosum

II DEVELOPMENT Each hemisphere is a vesicle evaginated from the telencephalon just posterior to the lamina terminalis Each consists of a greatly expanded pallium, and two gray basal structures, the olfactory lobe anteriorly, and the corpus striatum attached to the lateral wall of the thalamus

A The Pallium is an extensive lamina which develops a gray cortex by migration of ependymo-mantle elements across the marginal layer It becomes separated into two major regions by the *rhinal* and *hippocampal* fissures

1 The Archipallium (olfactory cortex) includes the *pyriform area* with olfactory gyri and hippocampal structures It lies in the medial part of the basal surface of each hemisphere

2 The Neopallium grows extensively, and expands back over the thalamus and midbrain It forms five major regions, the frontal, parietal, occipital and temporal lobes and the insula of Reil The insula lies against the striate body, and grows least, becoming covered by the operculae of the tem poral and frontal lobes

B The Olfactory Lobe remains small and attenuated in man Located in the ventral surface of the frontal lobe, it receives the short olfactory nerve fibres and connects with the archipallium and other parts of the rhinencephalon

C The Corpus Striatum is formed from the mantle layer at the base of the hemisphere and fuses with the lateral wall of the thalamus The striatum becomes divided into *caudate* and *lenticular nuclei* by the cortical projection systems (*internal capsule*) which grow through it

D The Commissures between the hemispheres develop in the lamina terminalis

1 The Anterior Commissure consists of an anterior part con

necting the two olfactory lobes, and a larger posterior part between the pyriform areas of the temporal lobes

2 The Hippocampal Commissure develops close to the anterior commissure, but is later carried back with the splenium of the corpus callosum It connects the hippocampus of each side

3 The Corpus Callosum develops close to the preceding commissure, but its great growth carries it up and back, stretching part of the lamina terminalis into the septa pellucida connecting with the fornix It connects the large neopallial parts of the hemispheres

III ORGANIZATION The cerebral hemispheres may be divided arbitrarily into phylogenetically old parts connected with the olfactory system (rhinencephalon) and the newer parts culminating in the highly developed neocortex

- A Old Structures
  - 1 Basal—Olfactory Lobe, amygdala (archistriatum)
  - 2 Surface—Archicortex (principally the hippocampus)
  - 3 Connections
    - a Projection—Fornix
    - b Commissural—Anterior and hippocampal commissures
- B New Structures
  - 1 Basal—Corpus Striatum
  - 2 Surface—Neocortex
  - 3 Connections
    - a Projection—Internal Capsule (afferent and efferent)
    - b Commissural—Corpus Callosum

IV THE CORPUS STRIATUM develops from a nuclear mass in the basal wall of the hemisphere, which becomes folded back and fuses with the lateral wall of the thalamus The striate body forms an elongate rounded mass, consisting of a small wedge shaped globus pallidus or *paleostriatum* and a much larger *neostriatum* The cerebral projection systems grow through the neostriatum, separating it into a dorsally arched *caudate nucleus* curving around the outer border of the thalamus, and a lateral *putamen* to which is attached the *globus pallidus* The separation formed by

the projections (the *internal capsule*) is not complete, the caudate and putamen remaining attached anteriorly

A Structure.

1 The Caudate Nucleus consists of a large head, the lower part of which (paleo-caudate) is closely associated with the olfactory anterior perforated substance and amygdala nucleus The rest of the head (neo-caudate) continues back, becoming attenuated, into a body, and tail which curves ventrally around the posterior part of the internal capsule, and ends anteriorly close to the junction of the head with the putamen It is closely related to the lateral ventricle, forming the lateral wall of the anterior horn and body of the ventricle, and lies in the roof of the inferior horn It consists of both small and large neurones

2. The Putamen is an oval nucleus, rounded laterally, and with concave medial surface separated from the globus pallidus by a thin fibre stratum, the lateral medullary stria It consists of large and small cells

3 The Globus Pallidus is a wedge shaped nucleus with base against the putamen, and apex toward the subthalamus It is divided into a medial and a lateral division by the internal medullary stria It consists of large motor type neurones The putamen and globus pallidus form the *lenticular nucleus*

B Connections

1 The Caudate nucleus receives fibres from the medial nucleus of the thalamus, cortico-striate fibres from the frontal lobes (areas 6 8 and 9), and collaterals from the adjacent cortico-bulbar spinal system It sends short internuclear fibres to the putamen and globus pallidus

2. The Putamen receives many fibres from the caudate nucleus and cortico-striate (extrapyramidal) fibres, as well as collaterals of cortico-bulbar spinal neurones It sends short internuclear fibres to the globus pallidus

3 The Globus Pallidus is the efferent part of the striate body The caudate and putamen receive fibres from various sources which they relay to the globus pallidus which also receives some cortico-striate fibres Efferent fibres form strio-fugal connections with the hypothalamus, the centro-

median and subthalamic nuclei, the zona incerta, the red nucleus and substantia nigra, nuclei of Darkshevitch and Cajal, and lower bulbar centers They form two major bundles, the *ansa lenticularis* containing fibres passing ventrally around the medial border of the internal capsule, and the *lenticular fascicle* (H_2 of Forel) containing fibres passing through and dorsal to the internal capsule to enter the subthalamus

V THE CEREBRAL CORTEX is a nuclear stratum developed in the outer layer of the pallium In thickness it varies from 1.5 to 4 mm and in extent from 2000 to 2500 sq cm Beneath it lies the medullary substance, consisting of projection, commissural and association fibres The gyri and sulci are foldings of the cortex into the medullary substance

A Structure. The neocortex consists of tangential laminae of nerve cells and fibres, pierced by small radial (perpendicular) columns of fibres

1 Baillarger's Lines are two prominent fibre strata present in most of the cortex The outer stratum is thickened in the striate cortex (area 17) to form the *stripe of Gennari*

2. The Radial Columns consist of entering afferent fibres as well as the efferent pyramidal and spindle cell axons

3 The Cortical Cells consist of four types based upon their axon process

a Descending axon cells

(1) *Pyramidal cells* are cone shaped, each oriented with *apical dendrite* toward the surface, and basal axon entering lower cortical layers or the medullary substance *Collateral dendrites* extend from the apical dendrite, and *basilar dendrites* from the cell body There are small, medium, large, and giant pyramidal cells with short, medium, and long apical dendrites

(2) Spindle (fusiform) cells have a *shaft dendrite* (short, medium, or long) extending toward the surface, and axon entering the medullary substance *Collateral* dendrites extend from the shaft, and *basilar dendrites* from the cell body

VI The Polymorphic Layer contains spindle, star, and granule cells Long spindles have intralaminar basilar and collateral dendrites, with unbranched shaft reaching Layer I The shafts of medium spindles reach Layer IV, of short, Layer V The axons enter the medullary substance

5 The Fibre Components of cortical laminae consist of four types cortical afferent, dendrites of cortical cells, axon collaterals, and the axons of intrinsic neurones, the whole forming a dense neuropil

a The afferents include commissural and association fibres of the cortex as well as thalamic afferents

(1) The specific thalamic afferents originate in thalamic nuclei, ascend as myelinated fibres to Layer IV, where they branch into a dense plexus, some fibres reaching Layer III

(2) General thalamic *afferents arise as* collaterals of fibres in the medullary substance, ascend with sparse branching as far as Layer II or I The parent fibre reaches more than one cortical area

(3) Commissural and association fibres arise in contra- and ipsi lateral cortex Their sparsely branching fibres end in Layers VI, III, and II

b The dendrites of cortical cells have been considered above under the specific laminae Basilar and most collateral dendrites end in the same lamina in which the cell is situated Apical dendrites reach Layer I, sometimes with extralaminar collaterals Medium length apical and spindle shafts distribute collateral dendrites in two or three layers Martinotti, granule and Cajal horizontal cells have intralaminar dendrites

c. Axon collaterals Collaterals of descending axons from pyramidal and spindle cells have extensive connections in specific cell laminae Pyramidal axons from Layers II and III have intralaminar collaterals, none to Layer IV, but many to Layers V and VI Axon collaterals from pyramids in Layer V form an intralaminar plexus (and to Layer VI) as well as extensive recurrent collaterals to Layers II and III Small pyramids of Layer V

often have recurrent collaterals more extensive than the parent axon process

d Short axons of Intrinsic Neurones include four types, and they form a major portion of the fibre plexuses of the laminae

(1) Granule cells (Golgi Type II) are found in most laminae, but mainly in Layers II and IV Their short highly branched axons end in a small dense region

(2) Descending axons (short) include those from pyramid cells in Layers II and a few in IV They end chiefly in Layers V and VI

(3) Ascending axons (cells of Martinotti) are distributed in a variable fashion to most laminae

(4) Horizontal axons (cells of Cajal) are found only in Layer I They receive connections from ascending and recurrent terminals, and end on apical dendrites or on small cells of Layer II

6 Descending Axons include projection, commissural, and association fibres (besides the short intracortical connections)

a Projection fibres originate primarily in the pyramidal cells of Layer V Most run in the internal capsule and include cortico-bulbar, spinal, and pontine as well as fibres to the thalamus, striate bodies, red nucleus and substantia nigra

b Commissural fibres originate chiefly in the short pyramids of Layer V (and upper VI), and enter the corpus callosum

c. Association fibres form bundles in the medullary substance connecting various regions of the cortex They originate chiefly in the spindle cells of Layer VI Some arise from long axon stellate cells in the same layer and take a short U course to a neighboring gyrus

B Cortical Areas The cortex is divided into many regions which differ in cytoarchitecture in their afferent and efferent connections, and in their time of myelinization There are thirty six chronologic areas (Flechsig) based on the latter, which may be grouped into primary (myelinating shortly after birth), inter

mediate, and late areas In general, these correspond to the projection cortices, the 'parasensory' areas closely around the afferent projection areas, and lastly the 'association' cortices Many of these variously defined regions are separated by limiting sulci

1 Architectonics Although the number of structural fields depends upon the criteria used by the investigator, the scores or hundreds are grouped into five types (von Economo) or nine regions (Brodman)

a The retrosplenal region includes the cortex connecting the cingular gyrus through the forniciate isthmus with the hippocampus Layers II and III are intermingled, as also are Layers V and VI It is concerned with the integration of olfactory and non-olfactory fibres

b The cingular region receives the olfactory projection from the anterior thalamic nucleus Layers II and III are distinct, and the anterior part of the gyrus is agranular

c The precentral region consists of very thick cortex anterior to the central sulcus It is agranular (Layers II and IV being occupied by pyramidal cells), and has no lines of Baillarger It is divided into a gigantopyramidal area (4) (close in front of the sulcus) with giant cells of Betz in Layer V, and a more anterior frontal agranular area (6) The axons of the Betz pyramids are contained in the cortico bulbar and spinal tracts The precentral region receives the cerebellar projection from the lateral ventral nucleus of the thalamus

d The frontal granular region occupies much of the large frontal lobes It has large granular (of small pyramid cells) and supragranular (correlative) layers Parts of the region receive fibres from the association nuclei of the thalamus, and give rise to the efferent cortico pontine tracts, and cortico thalamic and hypothalmic fibres The frontal pole has a well-developed ganglionic Layer (V)

e The postcentral region lies close behind the central sulcus It has well-developed granular layers ('overflowing into other layers), a thick Layer III, and only

small pyramids in Layer V It receives the general afferent projection from the posterior ventral nuclei of the thalamus

f. The parietal region grades off behind the postcentral without sharp demarkation Layer II is broad

g The insular region has well-developed Layers V and VI The supragranular layers develop late The underlying claustrum represents a detached or doubled Layer VI

h The temporal region is not clearly demarked from the parietal, but has a well-developed Layer IV Heschl's convolution (anterior transverse temporal) which receives the auditory projection from the medial geniculate nucleus, has very large pyramid cells in Layer III, and a thick granular formation

i The occipital region has a thin cortex with a great increase of granule cells in all layers The striate area (17) around the calcarine fissure has a double internal granular layer (and wide stripe of Gennari) which receives the optic projection from the lateral geniculate nucleus The peristriate area (18) has a much thinner Layer IV, and no stripe of Gennari

2 The Projection Areas are cortical regions in which end specific thalamocortical tracts, or in which arise descending tracts

a Afferent cortex is granulous (Type V of von Economo) with well-developed granular layers and many granule cells in other layers as well The specific thalamic afferents end in the internal granular layer

(1) The general afferent cortex (somaesthetic area) lies in the postcentral gyrus and consists of three vertical strips, areas 3 1 and 2 Fibres from the posterior ventral nucleus of the thalamus (carrying touch, proprioception, pain, and temperature fibres) end in the gyrus which in turn sends back corticothalamic fibres The contralateral spinal and cranial afferent roots are represented in inverse sequence along the vertical extent of the area Sacral dermatomes are highest with lumbar and thoracic

in the upper third, the arm and hand representations in the middle, and neck and face in the lowest third

(2) The auditory cortex consists of the anterior transverse temporal gyrus (of Heschl) which receives the geniculo temporal fibres from the medial geniculate nucleus, and to which it sends back cortico geniculate fibres Both cochlea are represented in each cortex

(3) The visual cortex consists of the striate area above and below the calcarine fissure on the medial surface of the occipital lobe It has a highly developed internal granular layer (with stripe of Gennari) receiving the specific afferents from the lateral geniculate nucleus, and sending back cortico-geniculate fibres There is a point to point projection of the latter nucleus in the calcarine cortex, and in turn homonymous retinal halves are spatially represented in the lateral geniculate nucleus Homolateral temporal and crossed nasal quadrants are represented in each striate area, resulting in an inverted crossed representation of the visual field The macular quadrants are represented at the occipital pole, the peripheral retina in the more anterior part of the calcarine fissure

(4) The cingular gyrus receives the projection from the anterior nucleus of the thalamus The olfactory cortex of the archipallium projects by the fornix into the medial mammillary nucleus, which in turn projects to the anterior nucleus It forms a pathway (olfactory ?) from archicortex to neocortex

(5) The precentral gyrus (motor cortex, area 4) receives the projection (cerebellar) from the lateral ventral thalamic nucleus

(6) The association cortex (prefrontal, etc) receives afferent fibres from the association nuclei of the thalamus

b Efferent cortex has well-developed subgranular layers (V and VI) which give rise to descending tracts

(1) The motor cortex is the gigantopyramidal area of agranular cortex (Type I of von Economo) in the precentral gyrus Beginning in the anterior paracentral lobule, it extends along the length of the central sulcus, but it is wider dorsally The large number of pyramidal cells and especially the giant cells of Betz give rise to the cortico-bulbar and spinal fibres (Some fibres also arise in post central regions 5 and 2) Fibres to the lower sacral level of the spinal motor column (postaxial muscles) arise in the highest part of the area, fol lowed by lumbar and thoracic T_1 to C_8 is repre-sented in the middle third, and the upper cervical and brainstem motor column in the lowest third of the area The latter are only in partially inverted order, and the eye muscles are represented in more anterior cortex The separate fingers and thumb have a very large representation Fibres from area 4 also run to the lateral ventral thalamic nucleus, from which it receives the large thalamocortical projection of the cerebellar dentate thalamic tract Other extrapyramidal fibres from area 4 (and area 6) form tracts to the pontine nuclei, substantia nigra, red nucleus, and subthalamus

(2) The premotor area (frontal agranular 6) con tains many pyramids but no giant cells of Betz It lies anterior to the motor area, and between them a narrow band with some Betz cells is called the strip area Projections from area 6 and some other adjacent or more distant areas are known as extrapyramidal because they do not run in the corticospinal or pyramidal system Fibres from areas 4 and 6 form the large precentro-pontine tracts, and they also include cortico-rubral, nigral, and subthalamic tracts Areas 4 and 6 have connections with the visceral motor (autonomic) column as well as somatic

(3) Extrapyramidal areas include various unrelated regions in addition to area 6 The posterior part of

the middle frontal gyrus (8αβδ) is connected with eye muscle nuclei, as is also peristriate cortex of the occipital cortex The cortico pontine tracts consist of a precentro pontine from areas 6 and 4, a prefronto-pontine (inferior frontal cortex), and a temporo pontine from the lower temporal gyri Cortico rubral fibres originate in postcentral areas 3 and 5 as well as precentral Cortico thalamic fibres arise from large regions of the cortex, especially in prefrontal 9 Cortico-striate fibres arise from large regions of the cortex, area 8 and especially in prefrontal 9

3 The Association Cortex consists of large areas, with prominent supragranular (correlative) layers, lying between the projection areas The prefrontal, and parts of parietal, occipital, and temporal lobes are included

a The frontal association area is greatly expanded in man The frontal pole has well-developed pyramid cells in Layer V, but they are small in the other frontal association regions Areas 9, 10, and 12 receive fibres from the medial thalamic nucleus and send back cortico-thalamic fibres Areas 8 and 9 (as well as precentral 6) give rise to cortico-striate tracts The region of the inferior frontal gyrus forms the prefronto-pontine system Fronto hypothalamic fibres are mainly from the basal part of the lobe

b The parietal association cortex receives and sends back fibres to the lateral thalamic nuclei Cortico-nigral fibres arise in area 5 and cortico-rubral in 5 and 3 Some corticospinal neurones from areas 5 and 2 run in the corticospinal tracts

c. The occipital association areas (18 and 19) receive fibres from the pulvinar, to which they return fibres Occipito tectal and occipito-geniculate fibres are also described

d The temporal association areas receive fibres from the pulvinar in area 22 and return temporo-pulvinar fibres The temporo-pontine tracts arise in the lower temporal gyri

VI THE MEDULLARY SUBSTANCE consists of a layer of white matter beneath the cortex, the great central mass of which forms the centrum semiovale The latter is formed by the bundles of callosal fibres intermingling with the projections radiating from the internal capsule The medullary substance consists of projection, commissural, and association fibres

A *The Projection fibres consist of the thalamocortical afferents*, and the descending pathways to the thalamus and lower centers Entering or leaving the hemisphere, the projections pass through the ***internal capsule*** between the caudate nucleus and the thalamus medially, and the lenticular (globus pallidus and putamen) nuclei laterally The capsule is divided into four parts, the *anterior limb in front of the lenticular nucleus* (be tween it and the head of caudate nucleus) separated by the *genu* from the posterior limb which is divided into lenticulo thalamic, retrolenticular and sublenticular divisions

1 The Anterior Limb contains the following tracts

a Afferent

(1) Thalamo frontal fibres from the medial nucleus to the prefrontal areas

(2) Thalamocortical fibres from the anterior nucleus to the cingular gyrus

b Efferent

(1) Fronto-thalamic fibres to the medial nucleus

(2) Fronto-striate fibres to the caudate nucleus and putamen

(3) Prefronto-pontine tract, passing into the medial segment of the basis pedunculi

2. The Posterior Limb (Lenticulothalamic division of)

a Efferent.

(1) The corticobulbar tract lies at the genu between anterior and posterior limbs

(2) The corticospinal tract lies posterior to the cor ticobulbar, the pattern forming head, arm, and leg in sequence

(3) The precentro-pontine tract also runs through the posterior limb

(4) Fronto-rubral fibres pass in this division, and cortico striate also

b Afferent The thalamo-parietal tracts to the postcentral gyrus are located posterior to the descending tracts They also are in spacial sequence

3 The Retrolenticular Limb contains the posterior part of the thalamo parietal projection

4 The Sublenticular Limb lies between the putamen above, and the lowest part of the tail of the caudate nucleus

a Afferent.

(1) The geniculo-calcarine tract passes laterally through the internal capsule Some of the fibres turn back over the tapetum of the posterior ventricular horn, and others turn forward forming a temporal detour over the inferior horn, the fibres passing in the external sagittal stratum to the calcarine fissure

(2) The geniculo-temporal passes laterally to the transverse gyrus of Heschl

b Efferent The temporo pontine tract enters the lateral part of the basis pedunculi

B The Commissural Fibres of the neocortex form the large corpus callosum whose fibres unite corresponding parts of each hemisphere The hippocampal and anterior commissures unite regions of the archicortex The callosal fibres arise from the short pyramids of Layers V and VI, and cross in the embryonic lamina terminalis Above the anterior commissure, they form the thin rostrum, the thickened arched genu, the body, and the rounded splenium roofing the transverse fissure The converging and diverging bundles (callosal radiation) of each side intermingle with those of the internal capsule (corona radiata) reaching all parts of the neocortex Frontal fibres pass through the genu, parietal fibres through the body, and occipital and temporal fibres through the splenium The latter form a thin lamina (the tapetum) roofing the posterior and inferior ventricular horns

C. The Association fibres include short and long bundles which unite various parts of the same hemisphere The short fibres form U shaped arcuate fibres connecting one gyrus with the next, or adjacent parts of the same gyrus The long bundles connect gyri in separate parts of the hemisphere

1 The Uncinate bundle connects the orbital gyri of the frontal lobe with the rostral end of the temporal lobe, by hooking beneath the sylvian fissure
2 The Superior Longitudinal bundle passes over and around the lenticular nucleus, connecting frontal with parietal, occipital and temporal gyri
3 The Superior Occipitofrontal arches along the caudate nucleus below the corpus callosum
4 The Inferior Occipitofrontal fasciculus courses ventrolateral to the lenticular nucleus
5 The Cingulum connects archipallial regions, the anterior perforated substance with the dentate gyrus, coursing through the cingular gyrus

VII THE RHINENCEPHALON consists of the olfactory lobe, the basal olfactory areas, and the cortical regions of the archipallium with their associated structures and connections Highly elaborated in lower forms, in man it consists of a number of small structures with complex relationships The olfactory structures form a ring or purse string system around the marginal rim of the hemisphere

A The Olfactory Lobe consists of an anterior bulb and a narrow tract which attaches to the hemisphere base in a triangular olfactory trigone
1 The Olfactory Bulb is an oval laminated structure embryonically hollow but solid in the adult
a The outer layer consists of unmyelinated axons of the neurones in the olfactory epithelium
b The inner layers consist of large *mitral cells* with apical dendritic glomeruli receiving the olfactory axons, of smaller *tufted cells* also receiving olfactory axons, and small short axon granule cells
c. The medullary substance consists of the axons of mitral and tufted cells which enter the olfactory tract
2 The Olfactory Tract enters the hemisphere at the trigone and divides into medial, intermediate, and lateral olfactory striae

B The Basal Olfactory Areas are secondary olfactory centers receiving the olfactory striae
1 The Medial Olfactory area receives the medial striae and

consists of the subcallosal gyrus and the parolfactory area (of Broca)

2. The Intermediate Olfactory area receives the intermediate striae and consists of the anterior perforated substance with olfactory tubercle, behind which lies the diagonal band (of Broca) connecting the subcallosal gyrus with the hippocampal gyrus

3 The Lateral Olfactory area receives the lateral striae It consists of the *pyriform* area separated from the neopallium by the rhinal fissure The pyriform area consists of the thin lateral olfactory gyrus which hooks around the lateral fissure as the limen insulae, and the hippocampal gyrus and uncus

C. The Archipallium consists of several gyri folded in along the medial border of the hemisphere, closely associated with which is the amygdala nucleus at the base of the striate body

1 The Hippocampal Gyrus forms the medial basal part of the temporal lobe, lying medial to rhinal and collateral fissures Posteriorly it is continuous through the fornicate isthmus with the cingular gyrus Anteriorly it forms the *uncus* hooked around the end of the hippocampal fissure which separates it medially from the dentate gyrus

2. The Dentate Gyrus is a small lobulated band on the medial surface of the temporal lobe, in the choroid fissure It is continuous dorsally around the splenium with the thin *supracallosal* gyrus (indusium griseum) covering the corpus callosum and ending in the subcallosal gyrus

3 The Hippocampus is an internal convolution in the floor of the inferior ventricular horn, and lies in the depth of the hippocampal fissure Medially it adjoins the dentate gyrus, and laterally it continues through the *subiculum* into the hippocampal gyrus

D The Archicortex is structurally distinct from the neocortex Its lamination is simpler and the layers are not comparable to those of the neocortex The general cell types, however, are similar

1 The Plexiform (molecular) layer consists of tangential fibre bundles and short axon cells

2. The Pyramidal layer consists of several sizes of pyramid

cells, with apical dendrite ending in the plexiform layer, and basal axon entering the medullary substance.

3 The Polymorphic layer consists of several elements including stellate and Martinotti cells.

E. Connections.

1 The Olfactory axons arise from neuro-epithelial cells in the nasal epithelium, pass through the cribriform plate into the olfactory bulb and synapse with the mitral and tufted cell glomeruli

2. The Mitral and Tufted cell axons form the olfactory tract consisting of commissural and projection fibres

a. The commissural fibres arise from tufted cells and cross in the anterior commissure to the opposite olfactory bulb

b. The projection fibres form the medial, intermediate, and lateral olfactory striae

3 The Medial Area receives the medial striae. The parolfactory area sends fibres over the corpus callosum (longitudinal striae) to the dentate gyrus The subcallosal gyrus sends fibres through the septum pellucidum and corpus cal losum, into the longitudinal striae to the dentate gyrus Fibres pass to the habenular nuclei in the medullary striae, and others pass to the tegmentum

4 The Intermediate Area receives the intermediate striae, and sends fibres in the medullary striae to the habenular nuclei Other fibres in the medial forebrain bundle reach the hypothalamus, and tegmentum The cingulum is a large band of fibres from the anterior perforated substance, through the cingular gyrus to the dentate gyrus.

5 The Lateral Area receives the main lateral olfactory striae, which end in the lateral olfactory gyrus, the uncus, and the hippocampal gyrus These gyri (the pyriform area) are sec ondary olfactory centers which send fibres to the hippocampus or projection cortex

6. The Subiculum and Dentate Gyrus are olfactory association areas sending fibres to the hippocampus.

7 The Hippocampus receives fibres from the olfactory receptive (pyriform) and association areas. The pyramidal cells send axons to the floor of the ventricle, where they form the

alveus or medullary substance The alveus continues into a long ridge, the fimbria, which becomes the fornix

a The projection fibres arise in the hippocampus, and course in the fornix around the thalamus, which it penetrates behind the anterior commissure to reach the medial mammillary nucleus Some fibres pass on to the tegmentum

b The commissural fibres cross in the hippocampal commissure to the opposite hippocampus

8 The Amygdala is a composite nuclear mass (the archistriatum) at the tip of the inferior ventricular horn It receives various olfactory neurones The terminal striae (arching medial to the caudate nucleus) are an efferent tract to the hypothalamic region Some cross in the anterior commissure

TABLES

NERVE				EFFERENT		
			Nucleus of Origin	Somatic	Branchial Arch	Autonomic
Special	I	Olfactory Fila				
	II	Optic (Br Tr)				
	VIII	Acoustic Cochlear Vestibular				
Somatic	III	Oculomotor	Oculomotor Edinger-Westphal	Mm. of Orbit		to Ciliary Ganglion
	IV	Trochlear	Trochlear	Sub. Oblique		
	VI	Abducens	Abducens	Lat. Rectus		
	XII	Hypoglossal	Hypoglossal	Mm. of Tongue		
Branchial Arch	V	Trigeminal Ophthalmic Maxillary Mandibular	Motor Trigeminal		Mm of Mastication Tensor tympani	
	VII	Facial	Facial Sup Salivatory		Mm of Face Scalp, Hyoid, Stapedius	Gr Sup. Petr to Sphen Pal. Gl. Chorda tympani to Submax. Gl.
	IX	Glossopharyngeal	Ambiguus Inf Salivatory		Stylopharyngeus (and upper pharynx?)	N tymp. and Lesser Sup. Petr to Otic Gl.
	X	Vagus	Ambiguus (Ventral Vagus) Dorsal Vagus		Mm. of Larynx and Pharynx	to Terminal Gl. of viscera, Card. Pulm Oesoph. Gast. Int.
	XI	Spinal Accessory Bulbar Spinal	Ambiguus Accessory (Cerv Cord)		Mm of Larynx Mm St.-Cl. Mast. and Trapezius	

COMPONENTS

AFFERENT			
General	Special	Ganglion	Terminal Nucleus
	Smell	Olfactory neuroepithelium	Olfactory Bulb
	Vision	Retina (ganglion layer)	Lateral geniculate
	Hearing Equilibration	Organ of Corti Scarpa's ganglion	Cochlear Vestibular
Proprioceptors in Orbital Muscles		Small ganglia along Oculomotor nerve branches ?	
Cutaneous and Ethmoidal Nasal and Facial Lacrimal and Auricular		Gasserian ganglion and Mesencephalic nucleus	Spinal (descending) and Principal trigeminal nuclei
Ramus auricularis Proprioceptors of Facial Muscles	Taste ant. 2/3s of Tongue via Chorda tympani	Geniculate	Nucleus solitarius (and Spinal trigeminal)
Ramus auricularis N. tympanicus Post 1/3 of Tongue	Taste post. 1/3 of Tongue	Superior Petrous	Spinal trigeminal ? Nucleus solitarius
Ramus auricularis Phar. Laryn. Card. Pulm. Oesoph. Ga.	Taste epiglottis	Superior (Jugular) Nodose	Spinal trigeminal Nucleus solitarius

TABLE II

THE VISCERAL NERVOUS SYSTEM

VISCERAL NERVOUS SYSTEM

- **AUTONOMIC SYSTEM** (Viscera Bl-Ves. Sm. Muscle Glands)
  - Sympathetic (Thoracico-Lumbar) System
    - Preganglionic (activating) (actually spinal)
      - from Spinal Cord (lat. horn) via White Rami Com. of T_1–L_2. Some continued in Splanchnic Nerves to Collateral Ganglia
    - Postganglionic (Sym. proper)
      - from Chain Ganglia
        - lat. brs. Gray Rami Com.
        - med. brs.—Plexuses around visc. arts
      - from Collateral Ganglia (preaortic) — Plexuses " "
  - Parasympathetic (Bulbo-Sacral) System
    - Preganglionic (long)
      - from Bulb
        - ________(Cr III)
        - ________(Cr VII)
        - ________(Cr IX)
        - Vagus___(Cr X)
      - from Sacral Cord Pelvic Visc. Nerve ($S_{2,3}$ or S_{3-4})
    - Postganglionic — from Visc. Gang. Cells located mostly in walls of viscera.
- VISCERAL AFFERENT FIBERS accompany both divisions of the autonomic system. Their cell bodies are located in the dorsal root ganglia of the spinal nerves and in the nodose ganglion of the Vagus. The fibers pass without synapse to the viscera. By definition, these afferent fibers are not designated autonomic or "sympathetic."

Note: This and the preceding table are taken from classroom charts through the courtesy of Prof. Charles V. Morrill of Cornell University Medical College.

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